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# Sediment and Water Quality: A Review of the Literature Including a Suggested Approach for Water Quality Criteria with Summary of Workshop and Conclusions and Recommendations

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# SEDIMENT AND WATER QUALITY: A REVIEW OF THE LITERATURE INCLUDING A SUGGESTED APPROACH FOR WATER QUALITY CRITERIA

by Robert N. Iwamoto Ernest O. Salo
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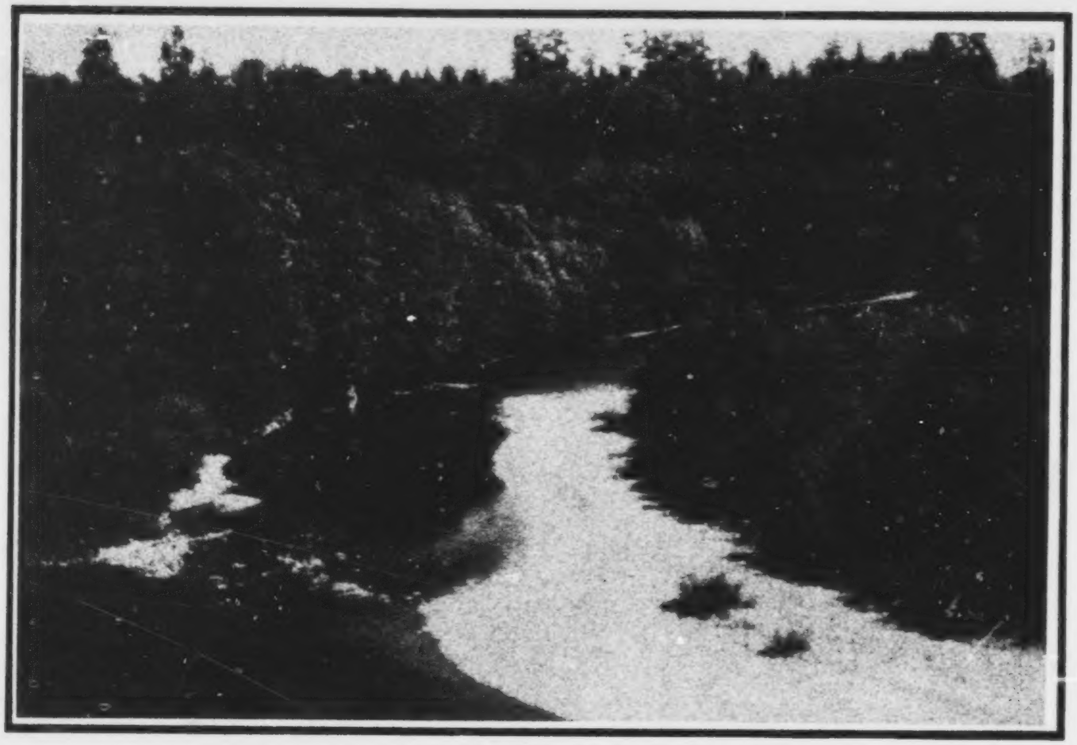

## with SUMMARY OF WORKSHOP and CONCLUSIONS and RECOMMENDATIONS

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16. ABSTRACT

A review of the literature dealing with physical and biological aspects of sedimentation in the lotic environment was compiled. Over 300 annotated and 100 unannotated references are included. These were used as a resource for a workshop on needs for an alternative to turbidity measurements as a water quality criterion. Also included are a summary of the current state of investigations on stream sediments and turbidity measurements as a criterion. These include: composition of bed material, behavioral aspects of aquatic fauna, and clinical measurements of physiological functions as a measure of stress. A suggested alternative was the establishment of criteria limiting the percentage of fines in the streambed. A workshop was held to discuss the technical and managerial aspects of the suggested criteria. A summary of the workshop with conclusions and recommendations is included. The more significant conclusions are that sedimentation of the stream's substrate, particularly the gravel used for spawning, produces significant detrimental effects on the salmonid resources. Turbidity measurements are useful indicators of general quantities of suspended sediment; but they are difficult to relate to biological significance. In relation to logging the Best Management Practices (BMP) concept appears to be the most practical, but BMP should be monitored by a set of criteria that are suggested.

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# PREFACE

Parts III through VII and Appendices B, C, and D of this report were initially prepared to provide participants of a workshop on sedimentation of streams and related water quality criteria with a review of the pertinent literature. The workshop was held to evaluate, from technical and managerial aspects, possible alternative approaches to criteria based on turbidity measurements. Subsequently, the summary of the workshop (Appendix A) and some conclusions and recommendations (Part II) were added. The bibliography contains 307 annotated and 112 unannotated references, some of which are cited in the text of this report. An additional 16 references which were not available for review have been included.

The report consists of six major sections:

1. Conclusions and recommendations which were derived from the bibliography and the workshop.

2. A review of the literature on sources of inorganic sediments, sampling techniques, predictive equations, effects on aquatic biota, and approaches for development of water quality criteria which have been suggested in the literature.

3. Research needs based on the analysis of the literature.

4. Recommendations for approaches for development of water quality criteria which were evaluated at the workshop.

5. A summary of the workshop proceedings (Appendix A).

6. The bibliography (Appendix D).

# I. INTRODUCTION

Numerous attempts have been made to determine the effects of sediments on aquatic organisms and, though often incomplete or inconclusive, they have contributed to the establishment of sediment criteria based on turbidity levels. Most are standards that do not allow amounts to exceed: 1) those which are considered ambient; 2) some arbitrarily determined numerical values in Jackson Turbidity Units (JTU's); or 3) some other measurement of light transmissibility. Although satisfactory as a first approximation in the establishment of judicial standards, the application of such criteria has led to confusion and disagreement.

Assuming that the use of turbidity levels as a water quality criterion is questionable, the problem became one of finding and of evaluating alternative approaches for assessing impacts on water quality. The conclusions and recommendations presented, although based on the review of the literature and the workshop, are subjective and not necessarily those of the participants of the workshop.

At the present time, some states have adopted forest practices which include the concept of Best Management Practices (BMP). This allows for the use of flexible standards which in practice may be the only practical approach. However, it is the concensus that BMP need not only updating but monitoring.

This report is intended as a base for continued investigation of alternative approaches.

## II. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations, although based on the analysis of the literature and upon the proceedings of the workshop, are necessarily subjective and not necessarily those of the participants of the workshop. In fact, agreement on criteria was not reached (and could not be expected in a 1-day session) and as the reader of the Summary of the Workshop (Appendix A) will conclude, unanimity on recommendations are unlikely. Thus, without additional collaboration with the participants, the conclusions and recommendations are presented. The first conclusion in particular is a judgment decision based on the literature as well as on the overall field experiences of the Fisheries Research Institute.

### Conclusions

1. Sedimentation of the stream substrate, particularly the gravel used for spawning, produces significant detrimental effects on the salmonid resources. The reproducible results in numerous laboratory and several test stream situations can be extrapolated to natural conditions. Extreme variation in results under natural conditions has precluded consistency; however, sampling in the field (Koski 1966, Tagart 1976) has included values obtained in the laboratory and test stream conditions.

2. Turbidity measurements are useful indicators of general quantities of suspended sediments. However, they are difficult to relate to any biological significance.

3. Direct measurements of suspended sediments, although exact, vary greatly with stage of hydrograph and with sequence of storms.

4. The tolerance of salmonids and other aquatic organisms to suspended sediments appears to be high.

5. Streambed composition--although variable with stage of hydrograph, sequence of storms (time of year), and location in stream--does reflect the instantaneous as well as progressive condition of the stream in relation to sediments.

6. Measurements of bedload, although technically valid, are too complicated as a criterion.

7. Currently, and probably in the future, the concept of BMP is the best management strategy.

8. BMP must be improved upon by monitoring, including the implementation of a set of water quality criteria.

## Recommendations

We recommend that:

1. BMP be monitored by a set of criteria including:

a. Turbidity units as determined by light transmissibility (JTU, NTU).

b. Limits to fines (to be defined as to size and quantity) allowable as intragravel sediment. The intragravel fines are to be measured by percentage composition by size categories.

c. Measurements of suspended sediments, including the relationships with turbidity and substrate composition (intragravel measurements).

2. Sampling of the streambed be standardized, by watershed, by:

a. Technique--the freeze core device appears to be the most promising.

b. Location--sections of the stream above and below areas of potential impact should be included as should the areas usable by salmonids for spawning.

c. Hydrograph--the sequence of storms should be studied and, as an example, the descending limb of one of the later winter storms should be chosen to compare with early summer, i.e., after the last storm.

3. A data bank of information received from recommendations 1 and 2 should be established.

4. A research program be started and continued to study the relationships of:

a. Intragravel fines and storm sequences.

b. Intragravel fines and stage of hydrograph.

c. Sources of natural sediments and deposition in the intragravel environment as related to a and b.

d. Sources of sediments from man-caused events (clearcut practices, roads, instream gravel operations), as related to a and b.

e. Measurements of bedload be related to intragravel environment.

f. The relationships of migrating salmonids to hydrograph and storm sequences.

g. The relationship of spawning and hydrograph stage.

5. The Environmental Protection Agency (EPA) should research and develop a method for evaluating the physical and biological effects of sedimentation and demonstrate proposed methods in cooperation with the

states. Development of standard methods for gravel sampling and other elements to be used in the "approach" should be a part of the study.

6. A companion effort should be the formation of an ad hoc committee of EPA and the states of Alaska, Idaho, Oregon, and Washington for review of the research progress and for development of an administrative program for BMP.

Recommendations 1-4 are based on the assumption that "natural" sediments may have a fate (deposition), that is correlated with storm events and stage of hydrograph, different from that of man-caused events (these may be more continuous). The life histories of anadromous fishes may be closely related to hydrograph and storm sequence as might be the suspension and deposition of sediments from natural sources. The impacts of man-caused sediments, if out of phase with hydrograph and the fishes adaptations, may be different than those of natural events.

## III. A REVIEW OF THE LITERATURE

### Definitions

The following definitions are from the report of the Subcommittee on Sediment Terminology (American Geophysical Union 1947):

"Suspended load can be used for either (1) the material moving in suspension in a fluid, being kept up by the upward components of the turbulent currents or by colloidal suspension, or (2) the material collected in or computed from samples collected with a suspended load sampler. (A suspended load sampler is a sampler which attempts to secure a sample of the water with its sediment load without separating the sediment from the water.) Where it is necessary to distinguish between the two meanings above, the first may be called the 'true suspended load.'

Bedload may be used to designate either coarse material moving on or near the bed, or material collected in or computed from samples collected in a bedload sampler or trap.

Bed material load is part of the sediment load of a stream which is composed of particle sizes found in appreciable quantities in the shifting portions of the streambed.

Washload is that part of the sediment load of a stream which is composed of particle sizes smaller than those found in appreciable quantities in the shifting portions of the streambed."

### Sources of Sediments

The source of all sediment transported by a stream is the watershed which the stream drains. Sediment may remain in storage in the channel bed and banks until critical discharges are exceeded and the sediment begins to move. Thus, the channel bed and banks may be considered a source of sediment for transport by a stream.

The erosion processes which are active in providing sediment to the streams from the watershed are:

1. Creep--slow mass movement of weathered material downslope under the influence of gravity.

2. Debris slides--rapid movement of unsaturated cohesionless material down a hillslope.

3. Debris avalanches--rapid slide or flow of saturated material.

4. Bank erosion and caving.

5. Overland flow--water that flows unchanneled over the soil surface because the infiltration capacity of the soil has been exceeded by rainfall intensity, a situation that does not occur in humid regions, except in disturbed areas.

6. Saturation overland flow--a situation where the soil becomes saturated with water, and the excess water is forced to flow overland, common on valley floors and in swales in humid regions.

The rates and relative magnitude of the six processes are dependent upon climate, geology, exposure, slope gradient, soil type, and vegetation cover. The yields of sediment to a stream are affected by the removal of vegetation, changes in runoff characteristics of the watershed, and changes in the cohesion of hillslope material. Human activities such as agriculture, urban development and construction, silviculture, and mining influence these variables in differing degrees of intensity and must be evaluated when considering sediment transport within watersheds.

## Sediment Sampling Techniques

It is somewhat artificial to speak of sampling bedload and suspended load separately because, during the process of sediment transport, an exchange of the two modes occurs, but this distinction is made for ease in separating field measurements.

### Suspended Sediment

The two main types of direct suspended sediment samplers are the depth-integrated and single-stage samplers. Depth-integrated samplers sample the water sediment mixture continuously while the sampler is lowered uniformly through the flow to the bed and raised back to the surface. The US DH-48 and US DH-59 are two handheld depth-integrated samplers used by the U.S. Geological Survey (USGS) (Guy 1970) and the U.S. Department of Agriculture (USDA) (Miller and Bowie 1965) to sample small and intermediate sized streams and are light, durable, and adaptable.

When streams cannot be waded, a cable and reel sampler (US D-43 or US D-49) may be used. Stability and safety are improved in the D-49 depth-integrated model.

A point-integrated sample can be obtained from deep or swift flows by holding the valve of the sampler open at specific points while integrating the stream depth in sections. These point-integrated samplers are more versatile than the depth-integrated variety, and are constructed so that the sampling valve operates electronically.

In the second method of sampling, single-stage samplers (US P-46, US P-63, and US P-50) are used to obtain sediment information on small fast-rising streams. They work on the principle that as a stream rises, the water sediment mixture enters the intake of the sampler until it fills the sampling bottle. These samples are affected by flow velocity, turbulence, and several other factors, but are used in flashy streams where normal sampling procedures are impractical.

Automatic pumping samplers have been designed to minimize the effect of changing flow velocity, although they increase the chance of malfunction by the dependence upon batteries as an energy source (Fredericksen 1969, York 1976). Other automatic samplers analyze sediment directly by measuring the bulk density of the water sediment mixtures or indirectly through electrical or visual tests (Skinner and Beverage 1976).

Indirect measurements of suspended sediments usually assume a correlation between suspended sediment concentration and turbidity, but recent studies have questioned the validity of this assumption (Duchrow and Everhart 1971, Larson and Wooldridge 1976). The USGS has decided to abandon "turbidity" as a measurement and will replace it with more precise optical measurements (Pickering 1976). Techniques to measure turbidity have varied from remote sensing and infrared photography (Rosgen 1976) to the use of Secchi disks. Duchrow and Everhart (1971) found the Hach Model 2100 turbidimeter the most reliable of several tested. With certain limiting conditions of particle size and suspended sediment concentration, optical properties can be estimated, but it is difficult to transfer the relationship from one environment to another.

### Bedload

Bedload samplers are more difficult to design due to the wide range of particle size to be sampled (from sand to cobbles and gravel) and because any instrument lowered onto the bed will change the flow and thus, the hydraulic characteristics at the sampling station. Also, sediment transport rates and flow velocity have a large range of natural variability in space and time, so where suspended sediment loads can be computed through the use of suspended sediment concentration and water discharge data, bedload estimates must include several flow variables in their computation.

Streamlined, pressure-differentiated samplers are designed to minimize flow disturbance by the instrument. The US BMH-53 and US BMH-60 are handheld samplers to collect bed material from fines to medium gravels. Pan-type samplers retain sediment that drops into slots after rolling up a ramp. Nielson (1974) rated several models of gravel sampling as follows:

| Type | Investigator | Efficiency (%) |
|---|---|---|
| Box basket | Muhlofers | 45 |
| | Swiss Federal Authority | 50 |
| | Nesper | 40 |
| | Ehrenberger | 60 |
| Pressure-differential box basket | Karolyi | 45 |
| | Vuv | 70 |
| | Arnheim | 70 |
| | Helley-Smith | to 90 |
| Pan type | U.S. Corps of Engineers | 70 |
| | Sirh | 70 |
| Pit and slot | Hubbel | to 100 |

Another technique for measuring the amount of bedload transported through a stream with a minimum of local disturbance is by surveying (Anderson 1970) or measuring the amount of sediment collected in a basin (Hansen 1973), trench, or slot (Renard 1976) across the stream. One difficulty is that sediment basins effectively remove sediment from the transport process, and so may cause degradation of the streambed downstream of the basin. Sills have also been used to force all the bedload moving over them into a collection device (Hansen 1973). These devices are inefficient in trapping fines, and periodically must be emptied out, the sediment weighed, and the streambed dug up.

Chains buried at known locations before high discharges can be checked afterward to establish the depth of scour and fill that occurred (Foley 1976). Radioisotope tagging is another technique useful in determining bedload movement in some cases.

For theoretical transport equations and biological considerations, the size distribution of the bed material must be known. One method is to push cores into the streambed, collect the material within the core, and sieve it to determine the size distribution of the material (McNeil and Ahnell 1960). Error may enter this measurement through the choice of sampling site, difficulty in obtaining samples of a uniform depth, and the introduction of fines while sampling (Cederholm and Lestelle 1973, Cederholm et al. 1976). A recent development uses the introduction of liquid nitrogen (Stocker and Williams 1972), carbon dioxide alone (Walkotten 1973, Walkotten 1976), or carbon dioxide dissolved in acetone (Ryan 1970) into a standpipe to freeze a core of gravel. Once removed and thawed, samples can be sieved by standard methods. Transportation of equipment to the sampling site and of samples to the base site may be a problem in some areas (Walkotten 1973).

The size distribution of the streambed material can also be obtained by measuring the size of sediment at points established by a grid (Wolman 1954, Williams 1975) and classifying these measurements into size categories. In gravel-bedded rivers, this method can establish the size distribution of the armored layer as well (gravel that protects the streambed from erosion until discharges are sufficient to move the protective layer). Investigators have expanded this technique to define the bed material in terms of particle shape, degree of imbrication, and gravel porosity, as well as particle size (Cooper 1965).

Alternative methods to measure bedload movements are by magnetic samples, acoustic devices that detect movement on the bed, photography, and ultrasonic sounding (Hubbell 1964). The sampling method used depends on the data required, the experimental situation, and the conditions for which the device was designed.

A discussion of the various hydrologic and hydraulic approaches used in determining sediment discharge is presented in Appendix A.

## Inorganic Sediments and the Aquatic Biota

The general effects of sediments have been well documented in the literature. Several reviews (Cordone and Kelley 1961, Hollis et al. 1964, Everhart and Duchrow 1970, Phillips 1971, Koski 1972, Gibbons and Salo 1973, California State Water Resources Control Board 1973*b*, Meehan 1974, Mortensen et al. 1976) are available.

In general, research on sediment effects has been selective to specific taxa. For obvious reasons, the majority of articles has dealt with fishes (66 percent) and fewer with other taxa--insects (23 percent), algae and phytoplankton (8 percent), and invertebrates other than insects (3 percent). Those percentages, while pertinent only to this report, may be considered representative of the available literature.

Sedimentation has the potential of affecting aquatic organisms by:

1) clogging and abrasion of gills and other respiratory surfaces;

2) adhering to the chorion of eggs;

3) providing conditions conducive to the entry and persistence of disease-related organisms;

4) inducing behavioral modifications;

5) entombing different life stages;

6) altering water chemistry by the adsorption and/or absorption of chemicals;

7) affecting utilizable habitat by the scouring and filling of pools and riffles and changing bedload composition;

8) reducing photosynthetic growth and primary production;

9) affecting intragravel permeability and dissolved oxygen levels;

10) affecting the fishing for and catachability of sport fishes.

As implemented criteria might be based on effects on specific taxa, we have attempted to treat taxonomic groups separately with respect to suspended sediment and bedload (including settleable sediment) effects.

## Algae and Phytoplankton

Inorganic sediments can affect algal and phytoplankton communities by bedload movement and by changes influenced by suspended and deposited particulates.

Excessive shifting of bed material may remove algae by grinding and dislodgment (Chapman 1963). Nuttall (1972) determined that the constant shift of sand (0.3-0.599 mm) along the riverbed after 10,000 m$^3$ had been deposited was primarily responsible for the lack of aquatic algae and macrophytes in the River Cornwall, England.

Suspended sediments produce more varied effects. They can decrease penetrant light transmission, thereby reducing the depth of photosynthetic activity (Chandler 1942, Chapman 1963, Cairns et al. 1972). Cordone and Pennoyer (1970) found a difference in algal pad concentration of 2.3/ft$^2$ to 8/ft$^2$ in silted and unsilted areas, respectively, above and below a gravel mill outfall on a California stream. Similarly, Herbert et al. (1961) reported a virtual absence of encrusting algae in Cornish streams polluted by china clay wastes. Buck (1956) noted that the average volume of net phytoplankton in surface waters of clear impoundments ranged from 8 to 13.8 times that in turbid water. Sediments from construction activities resulted in a reduction of transparency of about 50 percent as measured by Secchi disk, and were apparently responsible for a threefold reduction in algal productivity in a Virginia impoundment (Samsel 1973). In two studies on estuarine systems, Sherk et al. (1976) found significant negative correlations between carbon assimilation efficiency of four phytoplankton species and increasing concentrations of silicon dioxide representative of dredging, flood, and storm agitated sediments. Carbon uptake was reduced from 50 percent to 90 percent in those studies.

Suspended and settleable solids, by the reduction of photosynthetic activity and consequently, food web efficiency, can also upset population balances (Chapman 1963, Cairns et al. 1972). Samsel (1973) noted the disappearance of some algal genera associated with clear water and a decrease in total number of genera from 24 to 16 following sediment influx in an Oregon stream. Hansman and Phinney (1973) found a visual increase in chlorophyta associated with mud, silt, and logging slash after clearcutting.

## Invertebrates Other than Insects

Effects of sediment on aquatic invertebrates other than insects has received little attention. In a study of Mississippi River mussels, Ellis (1931) found that death of both adults and young occurred as a result of entombment or decreased oxygen, the latter caused by detrital decay. Herbert et al. (1961) noted the absence of gastropods and bivalves in streams with china clay wastes. However, oligochaete worms were found in all parts of clear and polluted rivers.

Although the reactions of their freshwater counterparts are essentially unknown, two species of estuarine copepods ingested significantly fewer numbers of food organisms with increasing silt concentrations. Those copepods typical of clean open waters were more affected than turbid water inhabitants, but the results could not be used to predict exposure times and concentrations required to cause serious population depletion (Sherk et al. 1974, Sherk et al. 1976).

## Aquatic Insects

The distribution of benthic insects inhabiting lotic environments is largely dependent on substrate particle size (Leonard 1962, Cummins and Lauf 1969). Species diversity and density are affected by the organisms' substrate preferences. These decrease progressively from rubble through gravel, muck, and sand (Cairns 1967, Sprules 1974, Pennak and Van Gerpen 1974). Riffle environments tend to support more diverse faunas and a greater standing crop of bottom organisms (Ruggles 1966). Rees (1959) found that Diptera preferred slow, sandy bottom areas, and Coleoptera selected moderate velocity sand-gravel mixture environments. Ephemeroptera, Plecoptera, and Trichoptera all showed a preference for swiftly flowing streams with gravel bottom habitats (Rees 1959, Gaufin 1962). Leonard (1962) stated that numbers and volume of mayflies were lowest in sand, increased through gravel, and reached a peak in coarse gravel, rubble, and mud suitable for burrowers.

There are several other mechanisms by which sediments appear to limit insect populations. Bed movement may dislodge or injure insects (Tarzwell 1938), remove vegetation used as food and cover (Rees 1959), or entomb sessile forms or life stages. Shifting and scouring of bed material also create unstable habitat (Tebo 1955, Nuttall 1972).

Though the effects of sediments on benthic insect populations remain unresolved, heavy deposits of sand and silt on stream substrates appear to be more detrimental than suspended material (Hamilton 1961, Brusven and Prather 1974). Deposited sediments may produce a gasket effect around cobble, reducing accessibility of microhabitats (Brusven and Prather 1974), or limiting intragravel waterflow (Ziebell 1960).

Nuttall and Bielby (1973) found large changes in species composition and density associated with deposition of fine inert solids rather than turbidity or abrasion caused by suspended material. Similarly, Bjornn et al. (1974) noted lighter densities of insects in riffle areas containing large amounts of sediments less than 1/4 inch diameter. Investigating the effects of landslide debris in the Clearwater River, Washington, Cederholm and Lestelle (1973) found a significant negative correlation between mean numbers of benthic invertebrates and gravel less than 0.841 mm. The bottom fauna population in control streams was nearly four times that of affected sites. Significant reductions were also observed below a gravel mill outfall in the Truckee River, California, the effect decreasing with distance downstream from the sediment source (Cordone and Pennoyer 1960). Herbert et al. (1961) reported a decrease of 3.3- to 19-fold in bottom invertebrates in streams with china clay wastes when compared with lightly polluted or clear systems. A field survey of logging practices in Alaska revealed a low species diversity of aquatic insects in Saginaw Creek which was believed to have resulted from siltation from improper removal of a logging bridge (Reed and Elliott 1972). Burns (1972) also observed immediate detrimental effects of sediment following logging road construction in California.

The extent to which various amounts of deposited sediments affect benthic faunas remains inconclusive. In fact, Tyler and Gibbons (1973), comparing a logged to an unlogged Alaska stream, determined that the greatest abundance of aquatic insects occurred in the logged system, despite its 5.5 percent higher concentration of fines less than 3.33 mm. Martin (1976) was unable to find a significant correlation between the standing crop of benthic fauna and inorganic sediments less than 0.25 mm in the Clearwater River, Washington. However, he concludes that this may have been due to sample sizes inadequate for the detection of small population changes. This observation may be valid. Chutter (1969) found that sediment-related changes in the invertebrate faunas of two South African rivers occurred without the benthos being smothered with inorganic debris.

Suspended particles may also be an important limiting factor, as they may abrade respiratory surfaces or dislodge insects and vegetation. Branson and Batch (1972) observed a 90 percent reduction in numbers and kinds of benthic fish food organisms at silt loads of 3,000 ppm from Kentucky strip mine operations. Roback (1962) noted parallel declines in caddis fly larvae. A 10-yr stream survey revealed that at sediment concentrations in excess of 500 ppm, numbers of genera decreased from 16 to 7. In field studies of a gravel dragline operation in the Wynoochee River, Washington, both Wagner (1959) and Ziebel (1960) reported decreases in the benthic productivity of about 85 percent at silt concentrations ranging from 91 to 103 ppm. Similar results were obtained by Gammon (1970). He found that the addition of more than 80 mg/liter of inert solids to the normal suspended particle concentration (approximately 40 mg/liter) could cause a 60 percent reduction in population density of riffle macroinvertebrates.

## Aquatic Vertebrates

Suspended Sediments. While investigations in this area have been fairly numerous, the results have generally been inconclusive. Many experimental designs have incorporated static bioassays, and in other cases quantification of effective sediment concentrations has either been lacking, inapplicable to natural conditions, or variable.

Wallen (1951), through a series of tests involving montmorillonite clay particles and their effects on 16 different fish species found impact levels were considerably higher than those usually found in nature. He concluded that under natural conditions, suspended montmorillonite clay particles were not lethal. Similar results indicating the nonlethality of high suspended sediment concentrations have been reported by Everhart and Duchrow (1970) for high natural runoffs in a Colorado stream; Herbert and Richards (1963) for coal washery wastes at concentrations of 50, 100, and 200 ppm; Neumann et al. (1975) for Patuxent River sediments and fuller's earth; and Jones (1964) for a variety of suspended inorganic and organic sediments. Cordone and Pennoyer (1960) found no differences, either in condition or numbers of nonsalmonids, between silted and unsilted waters below and above a gravel mill outflow site. McCrimmons (1954) found no appreciable effects of turbidities up to 1,150 ppm on parr stages of Atlantic salmon, and Hamilton (1951) reported that fish were seen in turbid regions of streams at almost any time of the year.

On the other hand, Pautzke (1937) exposed young rainbow and cutthroat trout to coal washings, and reported that death occurred within 150 and 30 min for the two species, respectively. No levels were reported. Buck (1956) reported that turbidity generally decreased growth rate, production, and reproduction of several spiny-rayed species (largemouth bass, bluegill, redear sunfish, channel catfish). The average total weight of fish in clear ponds (< 25 ppm) was approximately 1.7 times greater than intermediate ponds (25 to 100 ppm) and 5.5 times greater than muddy ponds (> 100 ppm). Differences in tolerance levels were also noted among the species.

Gammon (1970) observed that the mode of response, at least for several warmwater forms, was dependent on season and/or species. Those populations examined were generally most sensitive during the spring months. Langlois (1941) also reported that while pickerel, cisco, perch, and whitefish required clear waters, several other species were able to tolerate turbid conditions. Other species differences were reported by Sherk et al. (1974).

Stuart (1953*a*) observed differences in suspended solids effects relative to life stage. While brown trout ova placed in silty water "attracted" fine silt particles and consequently died, eyed ova and newly hatched alevins, through a variety of responses, were able to avoid deleterious effects.

Cooper (1965) has determined that "the flow of water can deposit silt within gravel although velocities exceed those allowing deposition on the surface." He also stressed the necessity for very low suspended sediment concentrations in waters flowing over salmon spawning redds. Slaney (unpublished material, from Parkinson and Slaney 1975) has apparently documented an instance where suspended sediment loads were inversely correlated (r = -.86) with survival-to-emergence of rainbow trout.

Suspensions of sediments of different constitution and size were also found to provoke different responses. Sherk et al. (1974) noted that while natural sediments tended to clog gill interstices, mineral solids coated gill epithelia preventing water contact. Larger particles clogged secondary lamellae and blocked circulation, creating dead spaces at points of primary gas exchange.

Although there are indications that relatively high turbidities may be tolerated in some cases, and serve as concealment during migratory movement (McCrimmons 1964), other observations indicated preferences for nonsilted waters and modifications of natural movements and migration. Smith (1939) reported that spawning chinook salmon, given a choice between silted and unsilted water, selected clear tributaries and a small clear stream rather than "muddy" waters. Servizi et al. (1969) and Mortensen et al. (1976) discussed the possibility that low oxygen and/or turbidity in a harbor or dredged areas could divert salmon runs from normal migration routes.

An indirect effect of sediments is that highly silted waters reduce fishing success. Tebo (1956) reported a decline in fishermen use of a stream after a reduction in water clarity as a result of logging. Buck (1956) also pointed out that clear waters attracted more anglers, increased catch-per-unit-of-effort, provided more desirable species, and enhanced aesthetic values. Decline in fishing success for those fishes which are primarily sight feeders has also been discussed by the European Inland Fisheries Advisory Commission (EIFAC) (1964), Servizi and Martens (1969), Koski (1972), and Meehan (1974).

Noggle* has completed the most comprehensive testing of direct and indirect effects of suspended sediments on salmonids; however, his results are in press.

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*Noggle, Charles A. In press. The effects of suspended sediments on juvenile salmonids as determined in a test stream. (Not exact title.) Fish. Res. Inst., Univ. Washington, Seattle.

Deposited Sediments and Bedload Processes. Generally, the investigations in this area have been more substantiated than others, although the ultimate impact on production is often obscure and not uniformly significant. Also, the modifications of bed material composition (including entombment or entrapment), bedload movement, and reductions in intragravel flow and dissolved oxygen concentrations often lead to indirect effects.

Bed material composition. Harison (1923) was among the first to correlate increases in egg and fry mortality with decreases in the size of particles comprising spawning redds. He also noted that only the strongest fry were able to escape very fine gravel when planted 8 inches deep. Similar results were reported by Hobbs (1937). Heavy mortality of incubating chinook salmon occurred in redds in which fine material (mainly clay) was present in the egg pockets. Through a series of experiments involving steelhead trout and coho salmon eggs, Shapovalov (1937) observed reductions of 50.1 percent and 38.0 percent in survival-to-emergence. The high mortalities were attributed to heavy siltation caused by flooding. Gangmark and Broad (1955, 1956), and Platts (1970) reported that high egg mortalities could be partially attributed to the smothering or blanketing effects of silt and sand on alevins. Shaw and Maga (1942) also observed that early and late additions of placer mining silt to incubating coho salmon eggs had differential effects. Silt added during initial stages of incubation resulted in low fry yields ($\bar{X}$ = 1.16 percent) and later emergence. Late silt addition (after hatching) reduced yield also, but damage was less extensive.

Neave (1947) attributed heavy mortalities of chum salmon eggs to streambed erosion and accumulations of silt on the bottom of a stream during periods of high water. Johnson et al. (1952), in an investigation of the effects of a landslide in the proximity of the Stillaguamish River, Washington, reported that an additional 10 percent loss of eggs and fry could be attributed to siltation in the river. McCrimmons (1954) correlated the degree of bottom sedimentation in gravelly, riffle areas with the percentage survival of underyearling Atlantic salmon. Sedimentation in pools resulted in low fry survival even when adjacent riffle areas were free from sediments. Shelton and Pollock (1966) were also able to demonstrate that low survival of chinook salmon eggs in an incubation channel occurred when 15 percent to 30 percent of the voids in the gravel bed were filled with sediment. Curtailment of reproduction of darters and minnows by siltation has also been reported by Branson and Batch (1972). Mating was apparently prevented and eggs and fry suffered heavy mortalities.

Burner (1951) observed that the size of chinook salmon redds varied inversely with the size of gravels in the spawning area and also with the amount of gravel cementation. Spawning generally took place in areas with high intragravel flow, and silt and clay cemented areas were avoided. Shelton (1955) reported that the percentage of coho salmon fry in artificial spawning channels was considerably higher in larger gravel (1 to 3 inches) than in gravel less than 1 inch in diameter.

McNeil and Ahnell (1964) found an inverse correlation between numbers of adult pink salmon returning to six Alaska streams and the percentage of gravel less than 0.833 mm. Spawners were also reported to be capable of removing a significant percentage of gravels less than 0.833 mm and tended to completely remove sediments less than 0.74 mm from spawning redds. From their studies, the investigators concluded that productive beds should contain no greater than 5 percent fines less than or equal to 0.833 mm, and that the presence of 30 percent or greater of fines in that category would constitute nonproductive beds. Shapley (1964) determined similar correlations (r = -.80) between the number of pink salmon fry produced and the mean fractions of gravel less than 0.833 mm.

Phillips (1964) reported species differences in the survival-to-emergence of fry. Emergence of steelhead trout and coho salmon was restricted at gravel sizes of less than 1/2 inch to 3/4 inch, and 3/4 inch to 1 inch, respectively. Gravel size was also reportedly effective in determining the weight of emergent steelhead fry, with only smaller individuals emerging from 1/4 inch to 1/2 inch gravel.

Koski (1966) found that the amount of fines in 21 individual coho salmon redds had the highest correlations with survival-to-emergence of all factors studied (gravel permeability, dissolved oxygen, and gravel stability). Fry in redds with greater amounts of fines completed development in shorter periods of time and had lower survival rates. The average sediment content in undisturbed streams ranged from 32 percent to 42 percent for fines less than 3.327 mm, and from 22 percent to 28 percent for those less than 0.833 mm.

From a field study of the survival-to-emergence of coho salmon in three tributaries of the Alsea River, Oregon, Phillips et al. (1966) found that survival ranged from 0 percent to 83 percent, with a significant decrease in survival in gravels less than 1/2 inch in diameter. Similar observations were noted for steelhead trout. Later experiments revealed that decreases in survival were directly related to the proportion of fines less than 0.833 mm in diameter. The authors also reported results obtained from experimental troughs. Fines of 1 mm to 3 mm were added in 10 percent increments (to a total of 70 percent) to gravels, in the composition normally found in redds. Survival was inversely correlated with the amount of added fines. Under natural conditions, the percentage of gravel less than 3.3 mm diameter was also negatively correlated ($r = -0.69$) with fry survival. Related results have also been reported by Hall and Lantz (1969) and Phillips et al. (1975).

Bjornn (1969) placed steelhead trout and chinook salmon eggs and "swim-up" fry in various sand-gravel mixtures (less than 1/4 inch diameter) under field conditions. Steelhead survived in greater numbers from gravel with higher percentages of sand than did chinook fry and eggs. The effects of sand were also determined to be greater with eggs. The author concluded that embryo mortality in gravels with 30 percent to 40 percent sand may approach 50 percent in chinook salmon and 30 percent to 50 percent with steelhead trout.

The effects of gravel size on larval behavior were reported by Dill (1969) and Dill and Northcote (1970). In aquaria experiments with two gravel sizes (1.9 cm to 3.2 cm versus 3.2 cm to 6.3 cm), the extent of downward larval movement was increased with the larger gravel. Survival was also apparently greater in the larger gravel, but condition (weight-length) ratio was poor. The increased survival was attributed to increased ease of gravel penetration, and decrease in condition to lack of support in the larger gravel. In an earlier study of chum alevins under field conditions, Dill (1967) noted that variation in gravel size, egg burial depth, or egg burial density could also affect emergence timing and patterns.

Burns (1972) studied four small streams in northern California to determine the effects of logging and road construction on fish populations. In one of those streams (Little North Fork Noyo River), an increase of 33.3 percent in sediments less than 0.8 mm was observed. Steelhead biomass decreased 42 percent; coho by 65 percent. Some of those decreases were attributed to high mortality and premature emigrations of yearling and older fish. Sculpins were also noted to decrease with heavy siltation but were quick to recover.

Cederholm and Lestelle (1973) examined the effects resulting from a landslide into Stequaleho Creek, Washington. No apparent differences were noted between landslide-affected and -unaffected areas for survival of cutthroat trout from eyed egg to hatching. Siltation levels for 3.36 mm and 0.841 mm fines were, however, found to be significantly higher than normal.

Koski (1975) examined fitness characteristics of chum salmon adults and their progeny. Through experiments with an artificial spawning channel, he was able to determine that decreases in emergence and fry fitness were correlated with percentages of sand (fines greater than 0.105 mm but less than 3.327 mm). For each 1 percent increase in sand, a corresponding decrease of 1.26 percent in survival-to-emergence was noted.

Slaney (unpublished, from Parkinson and Slaney 1975) determined negative correlations (r = -.78) between percentage of sediments less than 0.297 mm in spawning beds to survival-to-emergence of rainbow trout.

Tagart (1976) investigated the survival from egg deposition to emergence of coho salmon in eight tributaries of the Clearwater River, Washington. In the first year of the study, survival-to-emergence was inversely correlated with sediments less than 0.850 mm and positively correlated with sediments 3.35 mm to 26.9 mm. In the following year, however, no significant correlations were demonstrable.

The sole reference to sediment effects on nonfish vertebrates has been than by Branson and Batch (1972). High silt loads of 3,000 ppm were found responsible for the entombment of salamanders beneath cemented gravel and rocks.

Bed material composition has also been found to affect juvenile and adult fishes. Everest and Chapman (1972) assessed substrate types preferred by steelhead trout and chinook salmon. Differences in preference by age and species were noted. Underyearling and yearling steelhead preferred rubble, while underyearling chinook preferred silt. Earlier observations by Chapman and Bjornn (1969) showed that substrate and water temperature also determined downstream movement. Bjornn et al. (1974) reported that fewer age-0 steelhead trout and chinook salmon remained in channels with fully sedimented riffles (less than or equal to 1/4 inch granitic bedload sand) compared to channels with no sediment during the winter. Age-1 steelhead used pools for winter cover, while age-0 steelhead trout and chinook salmon sought riffle substrates. The addition of sediments less than 1/4 inch diameter led to reductions in the carrying capacity of a stream during the summer, effectively eliminating the presence of intragravel crevices for juvenile fish. In a much earlier experiment, Stuart (1953*a*) noticed that spawning brown trout avoided gravel containing fine sand silt or stones of uniform size.

Bedload movement. Bedload movement may affect survival-to-emergence by concussion of eggs during sensitive periods, scouring of redds, and exposing eggs from the protective confines of the intragravel environment, altering the pool-riffle habitats of streams, or by deep burial of intragravel developmental stages (Meehan 1974).

Gangmark and Broad (1956) found high mortalities of chinook salmon eggs apparently associated with the shifting and erosion of the channel and the smothering action of silt and sand during high flow periods. Severe floods also caused extensive gravel movement and 95 percent egg mortality in another investigation by Sheridan and McNeill (1960). Coble (1961) reported that considerable gravel movement can occur at least 10 inches below the streambed during the period salmonid eggs are in the gravel. Flooding and subsequent scouring of redds as a primary cause of mortality of eggs and larvae has also been implied by McNeil (1962). Sheridan (1967) noted that gravel removal from streambeds could accentuate instability and result in the removal or entombment of eggs in affected sections. Tyler and Gibbons (1973) attributed the low productivity of a salmon stream in Southeast Alaska primarily to abrasion from the movement of particles.

The International Pacific Salmon Fisheries Commission (1966) simulated hydraulic erosion by directing streams of water onto gravel in which sockeye eggs were planted. In the first experiment, a marked increase in mortality over controls was noticed. In a subsequent experiment, no significant effect was observed, possibly because of the advanced development of eggs or protection by gravel. Stages sensitive to physical shock were determined to be between fertilization and blastopore closure.

Intragravel waterflow and dissolved oxygen concentrations. Although treated separately, intragravel waterflow (permeability) and dissolved oxygen concentration are integral parts of any holistic approach in determining sediment effects. In general, positive correlations have been demonstrated between the two variables and survival of embryos. Vaux (1962) stated that the factors controlling the interchange of oxygenated water from the water column into the gravel beds include gravel bed permeability, gravel bed depth, bed surface configuration, and gradients in the stream surface profile. Phillips et al. (1966) reported significant interactions between dissolved oxygen and gravel size. Similar results had been reported by Peters (1962) with trout eggs in artificial redds subjected to natural siltation.

Cooper (1959) determined that sediments less than 0.3 mm were more effective than larger sediment in reducing flow in coarse materials. He also postulated that "the length of time required to kill eggs at critical levels of dissolved oxygen concentration is relatively short, and that mortalities observed from various lengths of exposure to silt deposition merely reflect a range of minimum flows obtained through the gravel."

Alderdice et al. (1958) exposed chum salmon eggs at various developmental stages to low oxygen levels at a constant temperature (10° C) for 7 days. Eggs were then removed to normal conditions. Among the results were: 1) oxygen levels below air saturation led to delays in hatching, greatest during early development and decreasing about the time circulation in the egg was established; 2) oxygen requirements were highest in early development, decreased to lower levels, and then rose slightly to a nearly constant level; and 3) median lethal levels for dissolved oxygen rose from 0.4 ppm in early development to 1.0 to 1.4 ppm prior to hatching.

Coble (1961), in a field study with steelhead trout eggs, also observed positive correlations between dissolved oxygen concentration of intragravel water and survival. Low embryonic survivals were also generally associated with low mean water velocities. Kingsbury (1973) however, found no significant relationship between fine sediment and intragravel oxygen.

Fry size at hatching and length of preemergent survival were also affected by dissolved oxygen concentration and rate of waterflow past embryos (Shumway et al. 1964, Jones 1964). Brannon (1965) found that sockeye alevins at 3.0 mg/liter required 2 weeks longer than those held at 6.0 mg/liter, and 3 weeks longer than those at 11.9 mg/liter to reach complete yolk sac absorption, although weights at time of emergence were nearly the same. Water velocity differences had no significant effect on embryo weights. Mason (1969) observed that coho salmon embryos and fry exposed to dissolved oxygen concentrations of 3 and 5 mg/liter were smaller at hatching and emergence, and had higher mortality during development that embryos and fry exposed to 11 mg/liter. Phillips and Campbell (1962) also found positive correlations between survival and mean oxygen concentrations. While larger alevins were noted at higher oxygen concentrations, no correlations between survival and mean gravel permeabilities of 2,110 to 25,400 cm/hr were noted. Wells and McNeil (1970) observed that the largest and fastest growing embryos and alevins of pink salmon were associated with spawning gravels with high levels of dissolved oxygen. Silver et al. (1963) noted that steelhead embryos at 9.5° C and chinook embryos at 11° C all died at oxygen concentrations of 1.6 mg/liter. Sac fry from embryos incubated at low and intermediate oxygen concentrations were smaller and weaker than those from embryos exposed to higher concentrations.

## IV. ANALYSIS OF PRESENT STATE OF THE ART

The National Technical Advisory Committee (1968) has defined criterion as "a scientific requirement on which a decision or judgment may be based concerning the suitability of water quality to support a designated use." With sediments, the establishment of criteria in that sense has been extremely difficult. Circumstances ranging from the principally nonpoint source nature of sediments (National Environmental Research Center 1975) to the stochastic variability of the amounts and conditions by which sediments are transported and impose their effects on aquatic life represent just some of the problems. Many states have attempted to circumvent those difficulties by establishing either turbidity and/or settleable solids criteria (*see* EPA 1972*a* and *b* for state-by-state compilations). Those policies, however, have not minimized the need for sediment criteria which are meaningful and applicable for water uses. A discussion of the problems inherent in establishing sediment criteria and some possible approaches from the literature follows.

### Problems in Establishing Sediment Criteria

Sediments are a natural component of the watersheds from which they originate. A problem lies in differentiating those changes wrought by natural causes from those of man's activities (Ziebell 1960). In some cases, high sediment levels are a necessity for adapted aquatic communities. Elimination of the pollutant in those cases may not lead to improvement and may drastically alter the morphology of the watercourse (Gessler 1975). Tolerance to deviations from optimal sediment conditions may differ at the species level, and possibly even for individuals of different ages of the same species (Ellis 1937, Bjornn 1968, Bjornn 1969, Hall and Lantz 1969, and Phillips et al. 1975).

In some cases, the impact of sediment additions on aquatic life has been minimal, and the resiliency of streams and aquatic communities effectively buffers any permanent changes (Bjornn 1974). Every stream may have the capacity, albeit a highly variable one, to flush sediments out of the system and restore conditions to normalcy. Merrell (1951) reported that stream bottoms disturbed by the clearance of logs and debris were restored to normal within a year. The unstable bottom of Little Bear Creek, Washington, caused by stream channel dredging, began to stablize by forming hard-packed bars and riffles within 2 months (Rees 1959). High flows removed silt from logging operations so that 5 yr after logging, the levels of gravel fines resembled prelogging figures (McNeil and Ahnell 1964). Saunders and Smith (1965) reported natural scouring removed large accumulations of silt, effectively preventing any lasting effects on resident brook trout populations. Shapley and Bishop (1965) analyzed substrate composition of four riffle areas in an Alaskan stream prior to and immediately after hydraulic mining, and again after flooding. Among results were: 1) moderate freshets are capable of removing fine materials from the streambed; 2) suspended sediments decrease at an exponential rate downstream; 3) the magnitude of streamflow can determine the streambed composition. Streams with high high flow:low flow ratios were more capable of removing fines than those with low ratios. From tagging experiments with substrate material, Brusven et al. (1974) determined that Emerald Creek, Idaho, was capable of self-flushing under natural conditions, but that until additional sediment sources were eliminated, the cleansing action was insufficient. Similarly, Platts and Megahan (1975) conducted a streambed monitoring program in the Idaho Batholith, and observed that once sediments from logging and ancillary sources were curtailed and a watershed rehabilitation program initiated, the percentage of fines decreased while gravel and rubble increased. Gammon (1970) cited a study in which adjustments of population density of macroinvertebrates were rapid, requiring only a few days to decrease significantly or return to normal. Meehan (1971), in discussing the effects of gravel cleaning with a "riffle sifter," reported that bottom fauna populations were initially reduced, but within 1 yr had returned to pretreatment levels. The adaptability of juvenile steelhead trout and chinook salmon was described by Bjornn et al. (1974). In that case, a creek with the highest proportion of sediments less than 1/4 inch diameter in riffle substrates, highest degree of embedded cobble, fewest benthic invertebrates, lowest species diversity index, and fewest drifting insects of three streams studied, had densities of juvenile steelhead and chinook as high as in the other study streams. Similar results have been reported by Alexander (unpublished) for a Michigan stream. Fish habitat was apparently ruined by artificial additions of sand, but the trout population remained in "good shape" by altering feeding patterns.

A serious limiting factor is our inability separate the effects of sediment from other environmental variables. Correlations in some cases are possible but in others, the relationships are ill-defined (Kingsburg 1973).

In defining the purpose of sediment standards as "maintenance of a viable river biota and of geomorphic equilibrium," Gessler (1975 and 1976) has specified three problem areas: 1) determining the extent of natural variations; 2) differentiating between man-influenced and naturally caused sedimentation; and 3) determining the effect induced by changes in sediment loads. He suggested that: 1) the entire spectrum of sediment sizes is important to biota and, as such, the ideal standard would incorporate "the sediment transport of each grain size as a function of water discharge or stage;" 2) by setting and enforcing standards for small streams, sediment sources may be identified by remote sensing; and 3) timing of sediment events often determines the extent of impact. The biotic and geomorphic characteristics of each region's streams and rivers should be integrated to determine applicable standards.

## Suggested Approaches from the Literature

Wurtz (1966) suggested that variations in response to environmental alterations, and classification of streams with criteria for each class should be established within each river system. The importance of having standards incorporate flow variations has been emphasized by Rice et al. (1975). The amount of sediment varies, dependent on whether the stream is rising or falling, and is a power function of discharge. Due consideration must also be given to: 1) complete specifications of performance characteristics; 2) simultaneous development of the standard and the monitoring scheme for judging compliance; and 3) development of statistical and analytical models to cope with variation and problems of serial correlation of sediment samples.

Cairns (1967) recommends that sediment standards be flexible because of the natural variation in suspended sediment loads and applicable on a drainage basin scale rather than for single streams. He suggests that the effect on aquatic organisms be used as a means of assessing suspended sediment loads. O'Connor and Sherk (1976) made a similar suggestion--that suspended sediment criteria should be established with due consideration for the most sensitive organisms and that the biological indicators be "determined for each proposed environmental modification." They state that, "data is difficult to compare because of different methods and approaches. In addition, the observed responses of organisms may not be due to turbidity or total suspended solids concentration, but to the number of particles, their densities, sizes, shapes, heights, presence, and types of organic matter and sorptive properties of the particles. Consequently, values such as ton/day, mg/liter, JTU, or extinction values which may be hydrologically satisfactorv from a water quality standpoint, may be insignificant from the standpoint of biological effects." Moring and Lantz (1974) suggested the use of long-term studies, when economically feasible, supported by short-term investigations. This ecosystem approach would tend to delineate changes which may not be immediately apparent.

Because of the greater ease of measurement, suspended sediments would seem a likely source of sediment criteria, but there has been little direct evidence to date of deleterious and lasting effects on aquatic organisms at naturally occurring and higher levels. Many aquatic organisms are highly mobile--vertically and/or horizontally--and thus, have the capability of evading intolerable suspended sediment levels.

It is the sessile, immobile forms in or on the streambed which appear to be susceptible. The Aquatic Life Advisory Committee (1956) stated, "adequate data are not available on amounts of inorganic materials which can be added to a stream without significant harm to its productive capacity. The direct effect of turbidity and suspended solids on fishes is not a satisfactory criterion since fish can withstand large concentrations without any apparent harm."

The size of particles carried as part of the suspended load varies with concentration. Gammon (1970) reported that when suspended sediment concentrations were low, 90 percent of the particles by weight were less than 10 μ in diameter. When concentration was high, more than 50 percent of weight consisted of particles greater than 20 μ in diameter. Wilson (1957) suggested that suspended sediment criteria should be set as "certain percentage increases above levels at normal low flow in waters." The EIFAC (1964) established suspended sediments criteria for principally spiny-rayed species of fish. The applicability of those limits may be questionable in light of some of the problems discussed previously. Finally, Bjornn (1974) suggested that the "amount of sediments that should be allowed to enter a stream before detrimental effects will occur on the aquatic habitat will depend on the amount of fines already contained within the stream channel. The amount that can enter the stream is the difference between the present level and the allowable, plus the amount transported."

The present status of the use of suspended sediments as the basis for sediment criteria continues to be a perplexing one, yet one that may hold promise if difficulties with estimation, prediction, determination of the relationship with streambed sediments, and long- and short-term effects on aquatic biota are clarified to the extent that reproducible results are obtainable.

Streambed integrity in the form of percentage composition of particles, scour and fill, and bedload movement has been shown to be a critical area as far as aquatic organisms are concerned. Several suggestions have been documented from the literature which might conceivably be valuable in determining sediment criteria. Wickett (1959) suggested the development of rating curves for gravels that have the best combination of use by adults, flow of water to incubating eggs, ease of fry emergence, and stability under as wide a range of discharges as possible. The requirements for ideal streambeds have also been proposed by Wagner (1961, reported by Shelton and Pollock 1966). "The ideal streambed for incubating salmon eggs would consist of gravel whose interstices (or voids) are just large enough to contain the individual eggs yet permit adequate percolation of oxygen-saturated water. This condition is met when all the gravel is spherical and of appropriate and uniform size, in which case about 35 percent of any given volume would be voids and 65 percent would be gravel." McNeil (1964) also suggested that spawning redds contain less than 10 to 15 percent fines for successful spawning. Tagart (1976) determined "good" and "poor" gravels for coho salmon emergence. "Good" gravel consists of sediments in sizes ranging from greater than 0.8 mm to less than 26 mm; "poor" gravel is anything less than 0.85 mm diameter. Relative to "poor" gravels, amounts in excess of 20 percent in the streambed lead to decreases in survival-to-emergence.

There are many other documented instances of the effects of sediment composition in streambeds. Many have been cited previously. Generally, sediments in size categories between 0.1 mm and 3.3 mm appear to be the most significant in impact. It seems obvious that once the relationships among fine sediments and other physical intragravel variables and intragravel biota are firmly established and unknowns resolved, bedload sediment composition may be a prime basis from which sediment criteria can also be established.

## V. RESEARCH NEEDS

The sources, transport, and relationships of sediment with biological populations will require substantial investigation before final workable criteria can be implemented. The role of sediment in aquatic ecology is highly variable and the literature is deficient in attempts at synthesis and in crossing disciplines. Research is needed on:

### Biological Research

1. Aquatic macrophytes, phytoplankton, and algae; studies on population dynamics, including recovery rates after impacts, and relative contribution of each group to the energy budget.

2. Invertebrates other than insects. This is perhaps the weakest area as far as background data are concerned. Any valid investigation of effects of sediment would appear to be an important contribution.

3. Insects. More field data on effects of sediment concentrations and particle sizes on species composition and density are needed. Sampling should be precise enough for the detection of small changes in community structure. This will require improved sampling methods for both the insect fauna and sediment concentrations (suspended and bed material) (*see* Recommended Approaches).

4. Vertebrates.

   a. Field investigations of sublethal effects on fish, including studies of physiological functions, should be conducted. The use of biochemical indicators such as chloride ion and glucose concentrations is of high priority. Continued studies of blood chemistry are recommended.

   b. Further investigations on conditions under which spawning and incubation are affected should be encouraged. Topics of high priority (*see* Recommended Approaches) include:

1) Clarification of differences in results between natural streams versus test streams and laboratory experiments.

2) Differentiation of the effects of multiple variables over long-term analysis.

c. Adaptations to sediments by individual and by population should be investigated.

d. Mechanisms by which postemergents of various fish species are removed from systems subjected to sediment influxes should be examined. Is the sediment directly or indirectly lethal, or do behavior patterns initiate an avoidance reaction?

e. Behavior of individuals, groups, and populations as indices of stress needs emphasis.

f. Differences in recovery rates of affected species at different sediment concentrations should be studied in test streams.

g. Vertebrates other than fishes (amphibians and some reptiles) should be studied.

Physical esearch

1. Techniques to measure the sediment load of rivers. Improvements are needed on sampling so that the conditions being measured are not disturbed and so that all ranges of the sediment load are sampled efficiently. A rapid, accurate measurement of suspended sediment is needed.

2. Fluid dynamics and the effects of sediment movement on the fluid properties of water.

3. The amount of sediment and its quality, which can be carried by a stream in excess of its normal load before the channel itself

changes, as well as on the basic relationships between transport and channel geometry.

4. The prediction of location and effects of scour and fill, more than in statistical terms, and upon the stability of stream channels.

5. More analytical modeling as opposed to empirical data correlation.

6. The mechanisms by which wind affects stream sediments.

7. The relationships between suspended sediments and bed material. This is of high, if not top, priority (*see* Recommended Approaches).

8. Methods of sampling the intragravel environment (composition, intragravel flow, and gravel movement). This includes the standardizing and updating of methods; i.e., construction of sieves with sieve openings based on the metric system.

## VI. RECOMMENDED APPROACHES TO BE EVALUATED AT THE WORKSHOP

Because of the demonstrable significant relationship between streambed composition and the eggs and larvae of fishes, as well as the relationship between the streambed and other aquatic organisms, we propose that the composition of the streambed be used as a water quality criterion. The composition can be expressed in percentages of particle size. While exact limits on the concentrations of the various sizes and shapes of sediments remain to be developed, there have been substantial data describing the deleterious effects of particles of sizes less than 0.850 mm in diameter when they exceed approximately 20 percent of the total.

In determining the limits on a geographical, i.e., demographically regional basis, the tolerance of organisms which are the most sensitive should be considered. Problems associated with a criterion of this kind include:

1. Naturally occurring levels of fines may be highly variable. Ranges may temporarily exceed 20 percent to 30 percent. Also, some biota may have adapted to levels representative of each stream or watershed.

2. Sampling techniques will have to be standardized. We recommend that a standardized technique utilizing the freeze core sampler be adopted.

3. The numbers of samples required to obtain levels of confidence is, of course, a variable. Care must be taken so that the samples are not collected and the diagnoses made after the damage has been done. In order to avoid this possibility, relationships between suspended sediments

and bed composition may have to be developed. Cederholm (personal communication) and Dunne (personal communication) have indicated that it may be possible to relate sediments suspended in the water column and in the bedload by the use of sediment rating curves. If further experimentation does indicate that the relationship is valid, and provided that the variability associated with sampling suspended sediments can be minimized, criteria based on the two sediment characteristics appear plausible. The synthesis of both sediment measurements in one criterion would be highly desirable to insure against the possibility that subthreshold levels of suspended sediments may accumulate over a long period of time in the streambed and exceed critical levels there.

4. Monitoring: stream-by-stream monitoring may be economically prohibitive. If it might be assumed that streams in a given watershed are similar, monitoring on a watershed basis may be reasonable. Extending our assumptions further, if streams possess certain physical and biological characteristics in common (hydrology, geomorphology, aquatic fauna and flora), then it may be possible to establish a classification scheme with monitoring conducted on the basis of a model stream approach. For example, data for such variables as rainfall, soil profiles, vegetation, instream fauna and flora, streamflows, channel morphology, would be collected, stored in data banks, and retrieved with the intent that streams with similar characteristics would be pooled into definite categories. On that basis, and depending on the ranges imposed on the variables, it might be possible to ha[illegible]e to 10 (more or less) general stream categories. Then, when proposed land-use activities are scheduled for a watershed, data for the potentially affected watercourses in the

area will be collected, compared with the previously established stream categories, and forecasts of potential effects and changes which might occur may be generated. This approach will particularly be effective in instances where premonitoring may not be possible, but data on changes which may have been caused by the particular land-use activity are desirable. Once initiated, the data bank will continually be updated with the results of each application.

Other alternatives: clinical, behavioral, and diversity changes as influenced by suspended and bedload sediments appear as distinct possibilities. However, our knowledge to date may be considered insufficient to establish criteria on these bases.

Although outside the scope of this report, we recommend that land management practices be reevaluated in terms of sediment production. Data collected by Cederholm (personal communication) in the Clearwater River Basin, Washington, indicate that a relationship exists between linear road miles in the watershed and the percentage of fines in the streambed.

## VII. SUMMARY OF LITERATURE REVIEW

1. A review of the literature dealing with physical and biological aspects of sedimentation was compiled to provide participants of a sedimentation workshop, held on March 10, 1977, with a summary of the current state of investigations in the area.

2. The establishment of sediment criteria on the basis of measurements other than turbidity may be difficult but not impractical.

3. The knowledge of the relationships of suspended sediments and aquatic life is incomplete and requires further investigation before criteria can be established on that basis.

4. Bed material composition (principally the percentage of fines less than 0.850 mm in diameter) appears to have a significant impact on primary and secondary productivity. Effects on spawning success of salmonids have been especially well-documented.

5. The body of the report points out research needs which we feel are most significant.

6. Alternative approaches to turbidity measurements as a criterion include: composition of bed material, behavioral aspects of aquatic fauna, and clinical measurements of physiological functions as a measure of stress.

7. At this time, the best alternative appears to be establishment of criteria limiting the percentage of fines in the streambed. A limit of 10 percent to 20 percent for sediments less than 0.850 mm is suggested.

8. Problems of sampling and monitoring are discussed and the need to develop a measurable relationship between suspended sediments and bed composition is proposed.

# APPENDIX A

# SUMMARY OF SEDIMENTATION WORKSHOP

Battelle-Seattle Research Center

March 10, 1977

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# APPENDIX A

## SUMMARY OF SEDIMENTATION WORKSHOP

### INTRODUCTION

The workshop on sedimentation and water quality criteria was held to evaluate possible alternative approaches to criteria based on turbidity measurements.

The workshop was divided into a technical session and a managerial session, each followed by a question and answer period including audience participation.

Prior to the workshop, members of the panels were given a set of questions to consider (Appendix) and they were also instructed to be prepared to give a short presentation related to the questions and to the main topic--are there criteria that can replace or support turbidity measurements? The summaries of the presentation are given.

The technical panel was composed of:

Chairman, Mr. Walt Rittall, EPA, Corvallis

Dr. Robert Bestcha, Forest Research Institute, Oregon State University

Dr. Ted Bjornn, Idaho Cooperative Fishery Unit

Dr. Tom Dunne, Geological Sciences, University of Washington

Dr. Ernest Salo, Fisheries Research Institute, University of Washington

Dr. Rudi Thut, Weyerhaeuser Company

The managerial panel was composed of:

Chairman, Mr. Don Lee Fraser, Department of Natural Resources, State of Washington

Mr. Ron Hansen, Alaska Department of Environmental Conservation

Mr. Edisal L. Quan, Oregon Department of Environmental Quality
(DEQ), Portland, Oregon

The Introductory Address was given by Mr. Daniel J. Petke, EPA, Deputy Director, Water Division, Region 10, Seattle, Washington

Wrap-up was given by Mr. Bob Rulifson, EPA, Region 10, Seattle, Washington.

Dr. Salo convened the meeting with:

"This workshop resulted from an EPA request to the Fisheries Research Institute for a literature survey for leads to a possible water quality criterion that might replace or augment the use of turbidity measurements."

Introductory Address - Mr. Daniel Petke. (A Summary.)

The water quality monitoring conducted by state pollution control agencies and others identifies turbidity as one of the water quality parameters most often violated, and the source of the problem seems to be largely of nonpoint source origin. The states are currently in the process of reviewing and revising their water quality standards as required by the Federal Water Pollution Control Act. The states and area-wide planning agencies are also involved in the water quality management program required under Section 208 of the Act. The point source standards have served their purpose well. In the area of nonpoint sources we begin to run into problems. Our specialists tell us that turbidity is only poorly related to suspended and settleable solids and tells us little about the effects of sediments on fish spawning and rearing. Should we consider a criterion to supplement water quality standards for protection of fish spawning in rearing areas from excess sedimentation? It is becoming increasingly apparent that nonpoint sources in addition to point sources must be controlled if the national water quality goals are to be achieved.

The concept of Best Management Practices has been developed, and these are commonly known as BMP's. The relationship of these BMP's to water quality standards now becomes of concern. Should they substitute for water quality standards, or should water quality standards continue to be in force when stream biolations are discovered?

The approach advocated in Region 10 is the three-pronged approach: First, in using the best knowledge available . . . a system of BMP's should be implemented for as many nonpoint source categories as possible. Second, new water quality criteria that reflect land management impacts on water quality should be developed. These will supplement the present water quality standards especially as they relate to sediment. Third, the new criteria should be used to monitor the effects of the applied BMP's on instream uses. With this approach, if the BMP's are established through a state regulatory program through permit or some other form of license, and the individual operator is complying with the BMP's set forth in his permit, he should not be subject to further requirements of water quality standards. It then becomes a burden of the regulatory agency to monitor the impacts on streams of the revised land activities and determine when BMP's should be upgraded and permits reissued with stricter controls.

"I want to make it clear we are not advocating the compliance with water quality standards to be waived, merely in favor of some other informal approach. . . . This is where we come back to turbidity as the water quality criterion in the monitoring parameter. And we find that it won't do the job protecting fish propagation in our Northwest streams. . . . We will have to find a better water quality criterion which more accurately reflects the impact of these sources on water uses. One immediate need is a better approach to evaluating the biological effects of sediment. . . ."

Question from the Audience:

There was a question as to the direction taken by EPA in general instream uses as compared to specific water quality criterion. Mr. Petke answered that, "I think EPA has attempted to direct more attention to instream uses and less attention to the specific water quality criteria. I know the regulations that we promulgated here within the last year or so made an attempt to do so and our guidance to the state has made an attempt to attract more attention."

## PRESENTATIONS BY TECHNICAL PANEL MEMBERS (SUMMARIES)

Dr. Salo described the report SEDIMENT AND WATER QUALITY: A REVIEW OF THE LITERATURE INCLUDING A SUGGESTED APPROACH FOR WATER QUALITY CRITERIA. He emphasized the sections on recommended approaches and showed slides on the relationships (Cederholm 1977) between the percentage of fines in the streambed and lineal miles of logging roads.

Dr. Bjornn's presentation was on the biological problems associated with sediment and the streams of the Idaho Batholith.

The Idaho Batholith, in the central portion of the state, can be characterized as an area with broad valley mountain streams, granitic soil, and steep canyons. These components coupled with washouts, natural blowouts, and the easily eroded soil present sediment problems of some magnitude. The material studied was low in organic constituents and ranged in size between 5 mm and 0.05 mm.

The potential effects of those sediments were described as:

1. Reduction in primary productivity.
2. Reductions in aquatic insect production and species composition from:
   a. Decreased primary productivity.
   b. Decreased entrapment of debris.
   c. Loss of suitable habitat.
3. Decreases in fish production from:
   a. Reduced emergence of fry.
   b. Reduced food production.
   c. Loss of habitat.

The results from several years of experimentation were summarized, some points of which may be applicable toward the establishment of future criteria. Gravel size becomes critical somewhere below 1/2 inch. In experiments with embryo survival, significant impact was noted when granitic sand composition was greater than or equal to 20 percent. For example, survival of chinook embryos decreased by 50 percent if sand comprised 30 percent of the bed material. Furthermore, 30-40 percent of the total volume of sandless gravel mixtures can be interstitial space or void area. If these void areas become filled with fine sediments, embryo survival becomes tenuous. The same might be said for postemergent fish. When voids become filled, substantial and significant reductions in fish, representative of decreases in carrying capacity, can occur. The relationship between percentage available area and the number of fish a stream will hold apparently applies to small streams only, and seasonal differences have been noted.

Correlational surveys were deemed inadequate in accurately assessing the effects of fines on fish. Some differences in insect density and drift would be associated with the amount of sediment in streams, but the technique failed with fish.

Finally, the amount of sediments in riffle areas was suggested as an index. Bjornn reported that this technique has been successfully used in some Idaho streams for controlling management activities.

Dr. Thut described the research on sediments conducted at the Weyerhaeuser field laboratory.

Weyerhaeuser has had studies underway since 1973 on the effects of fine sediment on various kinds of stream-dwelling animals. These include steelhead, coho, chinook salmon, cutthroat trout and a variety of benthic invertebrates. These studies have been primarily concerned with the impact of fine sediments in the gravel environment as opposed to open water. To a gravel matrix which was mixed beforehand, varying quantities of fine sediments were added to study the impact on salmonid fry emergence and upon aquatic invertebrates. There was a tendency (not statistically significant) for the finer fines (less than 0.8 mm) to have a more significant impact on the emergence success of salmon fry than the larger ones. The extent that these fines, within the interstices of the gravel, can reduce the ability of fishes to make it into the open water was the condition measured. The data, after testing by an analysis of variance, showed that there were thresholds of fines, defined as 0.8 mm, of about 15 percent for coho salmon and 20 percent for steelhead. At about 10 percent or greater the number of copepods can be significantly affected by the fines ($\leq$ 0.8 mm). They conducted the experiments to see if they could help the biologist to make some assessment of when the environment is in trouble and to see if they could shed any light on a criterion that could be used to measure performance--that is, a criterion that would have some legal status. In answer to the question asked beforehand whether or not a percentage of fines could be suggested which could be used as a regulatory criterion, Dr. Thut said, "I quite frankly don't think there is enough information just yet, although I kind of temper that, I believe there is probably 10 times more information on the biological effects of fines on gravel substrate than there is on the biological effect of turbidity. And that lack of information hasn't stopped anybody from promulgating a turbidity criteria. Additional work of that sort should be done and I think some decision should be made along the lines to what species are we going to direct our regulatory standards towards." Also, the measurement of fines in the gravel is a very time-consuming process. In order to demonstrate very subtle differences in the percentage of fines it requires an enormous number of samples. Eighty or 100 samples might be required to demonstrate a 5 percent difference at the 80 percent confidence level.

Dr. Thut suggested: 1) to work on the sampling problem; although the freeze core device is "quite an elegant instrument," much needs to be learned about the gravel environment and how the sediments enter into this environment before extreme variation can be evaluated; 2) more needs to be learned about the interrelationship between (current) flows, between different parts of the hydrograph, and the deposition of fines; once this is known, then the sampling can be stratified in time and space; 3) work should be done on the total spectrum of fines. We are measuring fines at 0.8 mm minus and it does seem to have some effect, but it is not to say that those gravels greater than 0.8 mm might not have some impact as well.

Dr. Bestcha presented his work on Patterns of Suspended Sediment Transport in Oregon's Coast Range Watershed.

"I'm not a biologist, so I'm going to be talking more in the physical realm on small streams and what I see happening there particularly in regards to suspended sediment transport." He illustrated some of the variability that he saw in reference to suspended sediment transport in these small streams, and illustrated some sediment transport patterns that he saw developing, particularly on a storm basis.

He emphasized the "tremendous" amount of variability involved in discharge and suspended sediment. Dr. Bestcha then quoted Rice, Thomas and Brown's paper (Appendix D, page 101) that stated that several thousand samples are often required to detect a 10 percent change in suspended sediment concentrations in a small mountain headwater stream. Dr. Bestcha stated that although there was a tremendous variability in these small streams, he could see very definite patterns emerging when they looked at the data closely: 1) higher turbidities with a given discharge usually occur on the rising limb of the hydrograph; 2) on the falling limb the turbidities are much lower at any given discharge level; 3) the turbidity curve also peaks prior to the peak of the hydrograph; 4) also in their particular study stream, turbidity is positively correlated with suspended sediment, so the argument can be made that the turbidity curve expresses relative changes in suspended sediment transport. Dr. Bestcha also emphasized the variability found from watershed to watershed.

Dr. Dunne, when asked to address the question whether it is possible to define the shape and size of streambed gravels within usable limits with just a few measurements, replied: "For about 20 years or more geologists have been trying to come up with some generalization about stream gravel shape and have abandoned the idea." So he referred to it as a dead end and talked just about size. He pointed out that there is a difference in the way a geologist usually measures the size of gravel substrate and the way fisheries people apparently do it with a coring device. He mentioned that the geologist's procedure is a "dirtier and rougher" procedure but that it yields results "that are comparable with sieving."

". . . We just walk around on a gravel bar, or in a pool, or on a hillside, wherever we're interested in the sediment and put our foot down and without looking run your finger over the front of your toe, pick up the rock you touch, pick it up, measure its intermediate axis, throw it over your shoulder and collect about 100 of these. Takes 10 minutes and the answer we get is the same as you get." Dr. Dunne said there are two general questions of interest, "What is: 1) the hydraulic roughness of the channel bed; 2) the gravel bar as a source of sediment once the armour layer has been stripped off?" In the case of the hydraulic roughness of the channel bed the precise composition of the surface is measured and in the case of the gravel bar as a source of sediment, after the top layer has been shoveled off the layer beneath is sampled. This allows only the sampling of fairly large particles. For example, it is very slow picking up pieces of sand 0.5 mm in diameter, so what they generally do is go down to about 4 mm. According to the literature there may be a relationship between survival of fishes in the composition of the gravel beds between 3.3 and 25 mm, and that just by altering the class of the mix on the frequency distribution and accepting a little bit less precision, the whole process may be sped up relatively." He says, "I don't know for sure whether it would work calibrated against your coring devices and if it doesn't work well it's too bad as it is a very quick procedure." Dr. Dunne then demonstrated a method of determining composition by looking at some data from local streams and plotting them by grade size against cumulative percent and showed that they were all approximately straight. And although the eight samples he demonstrated came from different parts of a disturbed channel at different times of the year over a 2-year period, the variability was not that bad. Then he demonstrated that you can calculate the mean and the proportion of grade sizes less than 0.85 mm within about 1 percent. So, in other words, the situation may not be near as bad here as in some of the cases mentioned earlier.

In summary he concluded that it may be possible with as few as 10 samples to define the mean within one-quarter to one-third of its value. He then discussed the importance of deciding where and when (in terms of the hydrologic year) the samples are to be taken. If the fish year is more important than the hydrologic year, then that should be considered.

## QUESTION AND ANSWER PERIOD FOLLOWING TECHNICAL PANEL--A SUMMARY

The question and answer period was conducted by:

Chairman Rittall. As an introduction to the question and answer session Mr. Rittall reiterated that the workshop is essentially predicated on the assumption, that, to ensure that BMP will be sufficient to protect the liability of Northwest streams, a stream sediment standard or a set of assessment criteria may be necessary.

Does the panel believe we have to have a stream sediment standard in addition to BMP, and if such a standard can be effective or will it do any more than give us a measure of after-the-fact effects?

Salo: "I can pass on that very easily. In the literature review that we completed we did not consider BMP. We assumed that we were charged to look for another criterion, and if we're looking for another criterion, what should it be? We settled on concentration of sediments in the streambed. Although I think that BMP should be the ultimate goal, BMP needs checking, and it needs checking from several sources. And as an alternate to measurements of suspended sediments I suggest the streambed as a criterion."

Bjornn: "The Forest Service in Idaho is using composition of fine materials in the streambed, particularly riffles, but they're also looking at the composition in pools as an index of the health of the stream. However, I think it's an after-the-fact type of measurement. . . . So I get the feeling that the ties between streambed composition and BMP are hard to tie down."

Bestcha: "I can see . . . monitoring after the fact as being very useful as indicating where you can improve management practices, but I'm not sure that it is such a good tool . . . because the linkage is not clear cut and I'm not sure that it can be used as a water quality standard."

Bjornn: "One of the things that we have to keep in mind is the ability of the stream to rehabilitate itself . . . so even the after-the-fact measurements can be misleading."

Dunne: "The question about a stream cleaning itself up is a complicated one; that is, it is more complicated than just looking at a point. If your stream cleans itself up, then someone else has gotten your sediment. . . ."

Salo: "Does it always have to be an after-the-fact measurement?"

Dunne: "I'm not too sure how difficult the coring method is, but running around sticking your fingers in the rocks--that method is very quick, but whether it would work to the level of precision you want, I think it will, then it's quick and easy to do."

Rittall: "If you have an established BMP and some sort of set of criteria, and if you are monitoring while activity in the watershed is going on and you see a degradation, what's your next step? Is it merely a correction to the BMP, or do you have assessments such as the possibility of the stream cleaning itself? . . . Perhaps this is what the Regional Office is after; a standard that would evaluate BMP and allow some modification, but not necessarily allow all the activity that goes on."

Rittall: "The second question on the list is: Do we really know how to determine if the nonpoint source sediment problem exists? . . . Do we have enough knowledge to determine . . . that sediments in the streams are the result of activity in the watershed so that if we see an adverse effect can we relate that to watershed activity and prescribe some level of control for the BMP?"

Thut: "It's not always possible. There are instances when you're dealing with small streams, and where in fact the headwaters are entirely logged, that it's really difficult to get any background in the sense that you could go above the activity. . . . To characterize a stream temporally you should begin to look at it 5 years before the activities have been planned and really study it under a variety of hydrological conditions . . ."

Bestcha: "I'm pretty hopeful that looking at sediment transport in streams that we begin to get a handle on sources. . . . I can see patterns developing in sediment movement. We can begin to identify what makes these patterns . . . in an undisturbed system and begin to make some comparable comparisons with a disturbed system, . . . but I'm not sure we're at that point yet."

Rittall: "The tie-in between the physical people and the biological people to work on this problem is one that we've been attempting to tackle in our laboratory and the question arises as to the type of information one needs from the other. For example, what do we need to know from the biologist?"

Salo: "Don't ask a biologist for a simple answer--for the dynamics of the biological situation is perhaps more variable than the amount of sediment that's coming down at some particular flow. But getting back to the practical, the physical people certainly should know or be able to get answers to the life histories of the biota in the stream. For example, it is possible to get some artifacts, like Dr. Bjornn pointed out, that make it appear as if regardless of the amount of sediment, regardless of the amount the pools covered, the population didn't suffer. That's because the population's already suffering from overexploitment and underescapement. These sorts of gives and takes are pretty rough."

Bjornn: ". . . I think we can throw the ball back to the physical people, the hydrologists, so to speak, for I think we are at the stage where, for example, we set the standard so that we're going to keep the spawning area in good condition, which means no more than 20 to 30 percent fines, then it's up to the hydrologist and watershed manager to find out how much sediment is going to come off from a particular operation, and how much is going to be deposited in the stream, and how much of it relates to the stream's transport capacity. . . . Also I think we are at a stage where we are able to tell the forest people where the impacts are going to be in our set of streams."

Thut: "I think I could foresee perhaps, in say 3 to 5 years, a biologist might have enough information to suggest some sort of fines criterion, for example a spawning ground. . . . With enough communication with the hydrologist we may be able to stratify our samples so that we might try to determine a mean value for the fines . . . for particular areas, for example where the current speed is just 1 ft/sec or 2 ft/sec and stratify it in that manner to get at a mean value that you could compare to a criterion."

(Audience) Tom Frost from Weyerhaeuser: "I feel a bit unsatisfied and unfulfilled with the answers you got from the first two questions . . . so for the first question: Is BMP going to achieve the result or does it need to be supplemented with some direct measurement of sediment and what sediment measurements are going to be made because we want to enforce those rules? The second question is: Can we segregate natural from cultural sediment sources by the rules we have set up which include BMP? . . . I would like to see the panel discuss these again more fully."

(Audience) Dave Rickert, DEQ, volunteered to answer Mr. Frost's questions. He discussed a questionnaire and the development of a matrix that they (DEQ) have used for looking at nonsource problems. The second thing that they are developing is a system of maps and overlays so that if you have a conceptual model of terrain types and management practices, you can return to the matrix ranking the terrain and the practices, and then this eventually leads up to BMP.

Rittall: ". . . The question still remains, do we need a standard as a backup to BMP? And as I gathered from this morning's panel, the answer was 'Yes'. . . ."

Bestcha: "I see a big difference between a standard and doing after-the-fact monitoring to understand what's going on and I really believe we ought to be monitoring after the fact what we've done out there. Now whether we are at the point where we can say that we can write that standard or not, I'm not so sure. But there is a big difference between monitoring a BMP and evaluating whether it's indeed doing the right job, and I don't think the BMP's ought to be etched in stone either. . . . I'm not sure that I'd agree that a standard will buy us everything we need to know."

Rittall: "I think that perhaps the word 'standard' is unfortunate because I have a feeling it's going to be more of a set of criteria, a set of parameters, rather than one number. The second question we asked was, 'Do we know how to determine the nonpoint source constituent of sediment in the streams?' If I can rely on my own judgment the answer was 'No,' we don't know. . . . We can't tell whether its 25 percent that's going to be affected by the BMP's. We have to do more before we can really relate what we see in the streams to the degree of control that BMP might need to accomplish."

Dunne: "The question which you stated is, 'Can you separate natural and cultural effects?' I would answer 'Yes' to that. I think you need to do a lot of work--it's hard, but you can do it . . . I think it can be done."

Bestcha: "Yes, but you need some kind of a tool to assess that change other than subjective interpretation. You need some statistical tools, such as time series analysis. . . . I think the information's there, but whether we can get to the point where we can get specific enough to say we have reached this point on any given stream that it's in violation, I don't know. That's a judgment decision. Somebody may want to make that, but I won't make it right now."

Bjornn: "I have concern about rigid standards and rigid practices for they are not transferable from one drainage to another . . ."

Rittall: ". . . It seems that in looking at gravel composition that we're relying pretty heavily on the egg and larval stages to set the criteria. If this is the requirement, one of the questions is: Is that sufficient to protect the other biota in the stream? . . . Today we have heard some 'No's' and some 'Yes's' . . ."

Salo: ". . . My feeling is that if we protect the spawning gravel during the spawning and incubation period, that most of our problems would be taken care of."

Bjornn: "I'll second that."

Bestcha: "I'll second that and perhaps say a little more. . . . However, I'm not sure that we should accept anything up to 20 percent . . ."

Thut: ". . . I think the approach that I'd suggest is to look at three different parameters: one would be the intragravel fines, the other would be turbidity. . . . I think it is the most accurate indication of any adverse impact that you would find on, say, something like photosynthesis. . . . Another indicator that is rather difficult to do is to get some measure of the intragravel chemistry . . ."

Bestcha: ". . . My feeling is that it (turbidity) is a very useful tool from the standpoint of sediment transport. . ."

There were further questions and answers and discussion by the Technical Panel.

# AFTERNOON SESSION OF THE TECHNICAL PANEL

In the first part of the afternoon session there was discussion among members of the audience as to sampling variability, methods of sampling, and the protection of first, second, and third order streams. Then there was a discussion by Dr. Dunne on the needs to set up a sediment budget for the watershed and to try to calculate what the stream can carry away easily and what will be left behind in the gravels. "And although it's not all that easy, it's one of the things that we can do at the present time, and one has to decide whether it's worth doing and whether it can be done on a routine basis."

One of the biggest contributors to variability has been the lack of field sampling personnel understanding the complications of mixing different kinds of sampling sites. The samples have to be tied in to the time of the year relative to the seasonal hydrograph and sampling specific physiographical locations within the stream. That is, always doing it at that place and at specific hydrologic sequences.

There was a discussion on the scouring needed to remove sediment from the streams.

Dunne: "I'm rather pessimistic on this point. I don't think in the foreseeable future we're likely to know enough about suspended load to be able to interpret turbidity measurements or suspended sediment concentration measurements. In terms of processes of cleansing the river channel or what's going on in the watershed . . . I'm fairly pessimistic about suspended sediment measurements."

Bestcha: "I feel just the opposite. I feel that there is a systematic way that these streams are moving material through them and it's the result of the summation of many different random processes at work out there."

(Audience) K Koski (National Marine Fisheries Service (NMFS), Juneau, Alaska): "I'm not sure how much of this discussion should be spent going over methodology and technique . . . Perhaps we can talk about that at a later time. . . . We do have a great deal of information and if we could standardize these techniques somewhat as Jeff has done, I think we would have a pretty good idea on what kind of criteria to establish. The precision of the freeze core is quite good and I feel that we can detect a 1 percent change and knowing that you have at least a 2 percent accuracy is good enough with this sampler and in a very homogeneous area the minimum number of samples would be about 15."

There was considerable discussion among the panel members and the audience on stream channelization, sampling methods, and the interrelationship of biological and physical systems.

(Audience) K Koski: "I want to make a comment regarding the criteria or the standard of using the streambed gravel composition. . . . I would recommend that we establish a criterion based on the ambient level of the stream sediments and that we select an additional figure, say perhaps 3 percent

> or so, that we cannot exceed. Now these would be in selected stream reaches or areas of prime concern, such as spawning habitat which we now know. And I present this as a recommendation rather than saying an overall load of 10 percent fines or additional 15 percent. I think we have to look at individual streams and at the ambient level and at specific locations in the streams, and have a maximum change of perhaps 3 percent."

There was continued discussion but this is the end of the question and answer session following the technical panel.

## TECHNICAL PANEL--CONCLUSIONS

1. Turbidity is one of the water quality parameters most often violated and the source of the problem seems to be largely of nonpoint origin (Petke).

2. Water quality criteria should be developed to monitor but not replace the concept of BMP's (consensus).

3. In the Idaho Batholith area the amount of fines in a spawning riffle has been used as an index for monitoring sedimentation. Studies in the State of Washington (Thut) have shown that fines less than 0.8 mm have more of an impact than do larger sizes on the emergent success of salmonids. There appears to be a threshold (of fines < 0.8 mm) of 15 percent for coho salmon and 20 percent for steelhead (Thut).

4. Some panel members (Thut, Bestcha) thought that we do not have enough information to support a criterion based on intragravel sediments although "we have 10 times as much as on the biological effects of turbidity. . . ."

5. Some participants (Thut, Bestcha) felt that an enormous amount of samples are needed to detect a 5 percent difference at the 80 percent confidence level.

6. Turbidity on a given discharge is higher on a rising limb of a hydrograph, and the turbidity peaks before the hydrograph peaks. Turbidity is positively correlated with suspended sediment (Bestcha).

7. One member (Dunne) of the panel felt that there may be ways to drastically cut down on the number of samples needed and still maintain enough precision for practical purposes.

8. The relationship between "fish year" and the "hydraulic year" needs to be determined (Dunne, Bestcha, Salo, Thut).

9. The biologists generally agreed that if a criterion should be chosen, it should be streambed material and it should be associated with the amount of fines in the spawning bed.

10. Three to 5 year's investigation on a stream may be necessary to get enough information for precise before-and-after study of changes in the spawning gravel.

11. A set of criteria is needed more than just one numerical standard.

12. To differentiate between natural and man-caused sediments as much as 5 year's background may be needed.

13. There are patterns in sediment movement and in order to get knowledge of sources and their amounts, continuity in research is necessary.

14. In 3 to 5 years biologists may have enough information to suggest some sort of fines criteria, for example in a particular spawning ground, and they may be able to stratify the samples in order to get precise results.

15. There was concensus that if the spawning gravels are protected during the spawning and incubation time, most of our problems would be taken care of.

16. There was disagreement as to the immediate usefulness of suspended sediment measurements (Dunne, Bestcha).

17. There were differences of opinion on the variability encountered and the confidence that can be placed in sampling of the spawning gravels.

One opinion (from the audience, Koski) was that we can detect a 1 percent change at 2 percent accuracy in a homogeneous (spawning) area with a minimum of as low as 15 samples.

18. A criterion of the ambient plus 3 percent fines was suggested by Koski.

## PRESENTATION BY MANAGERIAL PANEL--A SUMMARY

Fraser suggested that for the purpose of the meeting the panel would assume that the states are required to submit a 208 plan including the treatment of silvicultural activities that would meet the approval of EPA. The objective was to discuss the technical questions and how to go about devising and implementing a 208 plan that would meet the approval of EPA.

Fraser then introduced the panelists who each gave a short statement.

Ron Hanson outlined the normal sequence of functions that management and planners normally use. These steps include setting goals and objectives, with water quality standards as the intermediate goal, defining the problems as point source or nonpoint source, selecting alternatives for a permit system for point sources or BMP's for nonpoint sources, setting up policies and regulations and then monitoring to determine compliance and, finally, reevaluation of objectives and verification of assumptions.

Ed Quan proposed a team effort to find a common denominator to reduce the variables so one person doing the monitoring can get a good picture with a minimum of effort. If simpler tools were developed, the management agencies would be willing to test them.

John Spencer stated that Washington has begun its 208 planning process by forming water quality committees throughout the state. Some of the problems encountered include trying to set water quality standards that can be met by the rules and regulations for forest practices and the development of BMP for irrigated agriculture. He did not think we are ready to accept BMP as the best way to go. The difference between forest practices and agriculture is that a timber operation occurs once in 80 years or so and a farmer is concerned with practices that occur every year. The agricultural community that likes the idea of getting better practices on the farm is repulsed by the idea of effluent standards and treatment plant technology. We have come the full circle and still have not solved some of the real political and social problems.

Fraser: "You can see some of the problems administrators have. I'm taking the prerogative to ask some of the first questions. John, do you have the same kind of problem with the silvicultural area as you do with agriculture?"

Spencer: "We do feel the Forest Practices Act is the answer to the requirements of Section 208 of the Federal Act. The problem with irrigated agriculture is that we haven't defined the relationship between the general permit, effluent limits, and BMP's. You have set up an application process in forest practices with an estimated 6,000-10,000 applications a year. In Whitman County alone there are 1,700 separate farm operations. The big difference is the continuity of forest practices that agriculture doesn't have that doesn't lend itself to a permitting system."

Fraser: "Ed, you in Oregon have a Forest Practices Act. Ron, you are just in the process of getting this in Alaska."

Hanson: "Right. A bill was submitted again in January to establish a Forest Practices Act. As yet we have no regulations to implement the Act. The question we've been addressing today is whether we are satisfied with accepting BMP's or should there be some other criteria? Ed, do you like BMP's and how does that relate to the question of quality measurement that has been discussed here today?"

Quan: "I don't think we should be trying to squeeze more out of BMP's than is reasonable. I think the land managers should police themselves with the help of professionals to manage their resources."

Spencer: "I'd like to come back to my own mild argument and say that we should be getting the best from the man who has responsibility to manage the land. We run into a problem when we try to couple this with other requirements of the law, implementation, enforcement penalties, and so on. But I think there is a way out of this. The answer lies in the kind of political arrangement that's set up for implementation of BMP's. For example, I think the general permit concept that EPA has laid out is an opportunity for us to establish an acceptable political process to get BMP's into the place they are needed. Local implementation and local authority in getting BMP's on the land rings a bell with local people."

(Audience) Tom Frost (Weyerhaeuser Company): "How are you (John Spencer) going to judge the value of the rules under the Forest Practices Act in terms of perfecting water quality and biological integrity of streams? I think the people here are looking for you, as a DOE manager, to set up a standard to measure against."

Fraser: "John has a little disadvantage because he wasn't able to be here this morning. Our discussion so far today has revolved around silviculture activity and not the farming area. We went through the same participation process in the forestry community on a statewide basis. Ernie and some others made a proposal this morning that there might be some other criteria than the present water quality standards that might measure the effects of sediment on fish. He finds better correlation between survival of fish embryos and increase in fines in gravel than with turbidity per se."

Spencer: "I think there are two questions. One is the use of water quality standards as a measure of effectiveness of forest practice rules and regulations. The other is the use of water quality standards as an enforcement tool. I think we have come to a conclusion that the standards will not be used as the regulatory measure in forest practices or for agriculture. There's no question in my mind that we do need to add other criteria but we can do that more easily when we take standards out of the realm of enforcement. Our standards are very stringent and any violation we find is an enforcement tool. I think we have come to a conclusion that the standards will not be used as the regulatory measure in forest practices or for agriculture. There's no question in my mind that we do need to add other criteria but we can do that more easily when we take standards out of the realm of enforcement. Our standards are very stringent and any violation we find is an enforcement situation. If you set up some way of measuring variability over time, then I think you will be able to measure how valuable the (forest or agriculture) practices are. We have to keep in mind the beneficial uses and not become too concerned with criteria alone."

Hanson: "I'm in agreement that standards have to be changed especially when we find that a parameter such as turbidity doesn't really measure what we want."

Quan: "I'm in agreement with these fellows but I'd like to give a little background on what a turbidity (JTU) criterion has meant to us. Over the years we have been able to get the sand and gravel operations to work behind a berm except a dredge operating in deeper water. The public does not appreciate muddy water especially during the low-flow period and I think that if someone wants to do some instream work, at least he's aware that there is a standard and subject to enforcement. The only thing we ask is that they get in touch with the local biologist to find out if the timing of their project would have the least impact on the fishery."

Frank Rainwater, EPA, and others had a discussion on uniformity of criteria. Responses from John Spencer and others pointed out that there is an effort at uniformity through state water quality standards and the Forest Practices Act. In Alaska some of the miners would like designation of creeks for disposal of mining wastes.

George Snyder (NMFS) pointed out that there will be different problems if the fines are toxic or are organic. John Spencer explained that in setting stream classifications you look at natural characteristics and stream uses. JTU may not be relative to a particular use and there probably ought to be some other kinds of criteria included in the standard. Until we get over the administrative hurdles and take standards out of the front line of enforcement we are not going to be able to add these other criteria very easily. A discussion followed which confused effluent limits for a particular discharger with stream standards. The standard does not change with land usage like silviculture or mining.

(Audience) Jeff Cederholm (University of Washington) asked if the BMP's would apply to past practices. The discussion which followed concluded that the Washington Forest Practices Act was set up to apply to new operations and it is not clear whether it would apply to road maintenance. A stream typing system was set up as a basis for assigning practices for a particular stream. The scientific people are making progress in perfecting the cause and effect relationship between what happens on the land and what the impact is on the fisheries. Every forester will put importance on the relationship of emergence of fish from the gravel beds and the amount of silt. If we can see the cause-effect relationship, we will come closer together (in finding solutions). Robert Burgner (University of Washington) asked to what degree the BMP's for forestry are uniform statewide. Don Lee Fraser pointed out that there is flexibility in the rules a forester has to apply on the ground. In Oregon, the Department of Forestry is the sole agency regulating forest activities while in Washington there are a number of agencies. If there is an activity in the stream itself, then this has to be coordinated with fish and game departments.

Fraser: "We do favor the BMP approach rather than a number system down in the stream and we think that the land-use practices are the thing that has to be regulated. In is entirely appropriate that DOE and the other water and fisheries people should be measuring the effectiveness of the BMP's in meeting water quality standards and we welcome better ways to really evaluate whether we're meeting those goals."

John Spencer agreed with Fraser's summary and pointed out that the new criteria that are useful in cause and effect is where the greatest progress can be made. He said that water quality standards do have a place particularly where activities do not come under a management program.

Ron Hanson agreed with these remarks.

Rob Rulifson (EPA) gave a wrap-up stating that we have a ways to go in engineering and biological effects research but we are probably on the right track with this type of meeting. The next step is to assess our resources and proceed with the Corvallis Environmental Research Lab 5-Year Plan for research in this area. Their four main objectives relate to nonsteady state for quality, regional-type problems, broad relationships, and ecological effects of sedimentation. Our problem as a region is how to get regional and state input into the system. We will be working with the states to get their cooperation. Bob pointed out that there were many more experts in the audience that could have had more to say if it had not been crowded into 1 day. He thanked the audience for coming and the technical and managerial panels for their participation.

# MANAGERIAL PANEL--CONCLUSIONS

1. There was general agreement among the panelists that a Forest Practice Act is the answer to Section 208 of the Federal Water Pollution Control Act (control of nonpoint sources of pollution) for silviculture. One panelist (Spencer) pointed out that the many political and social problems of agriculture have not been worked out. He believes that a general permit is a way to establish an acceptable political process for implementation of BMP's.

2. There was a concensus that water quality standards will not be used as the regulatory measure in forest practices or for agriculture. Three members (Fraser, Spencer, Hanson) concurred in regulation of land-use practices rather than enforcement of a numerical system (water quality standards) in the stream.

3. There was unanimous agreement of the panel that there is a need for additional criteria for evaluating the effectiveness of forest practice rules and regulations. The water pollution and fisheries people should be measuring the effectiveness of the BMP's in meeting water quality standards.

4. The state pollution agencies (Alaska, Oregon, Washington) present at the workshop will cooperate in development of new approaches for evaluation of BMP and a meeting like this workshop is a step in the right direction.

## APPENDIX B

## SEDIMENT DISCHARGE COMPUTATIONS

### Hydrologic Approach

With a set of suspended sediment samples (and bedload samples if available) and corresponding water discharge data, one can relate concentration and discharge through a sediment rating curve, which is then used to estimate periods of mixing data or to extend records (Porterfield 1972). With knowledge of the frequency of discharges and concentration of sediment associated with them, total sediment discharge can be computed for a given period of time, i.e., Qs = Qw x Cs x K where Qs = sediment discharge (tons), Qw = water discharge (cfs) for the time period, Cs = concentration of suspended sediment (mg/liter), and K is a constant (0.0027).

But if a sufficient number of sediment samples is not available for a particular stream, estimates of the sediment load can be derived from theoretical considerations. Colby 1964, Graf 1971, and Stalnaker and Arnette 1976 present several approaches to this problem.

### Hydraulic Approach

#### Bedload Transport

Although the bedload makes up only 5 percent to 25 percent of the total load carried by a stream (Tywoniuk 1972), it is bedload transport that influences the scour and fill of streambeds and so determines the stability of the channel. Below a certain velocity or discharge, the bed material remains stable, and above that point, particles on the bed begin to move. This point is called the critical velocity, and cannot be defined precisely, except in a statistical sense. Initial motion is dependent on the particle size and the local shear stress which, in turn, is a function of the depth and slope of the water.

Historically, there have been three main approaches to the problem of sediment transport, later modified to fit particular situations. Numerous methods have been advanced to calculate sediment load, but many of these are applicable only in specific situations. The following discussion covers equations which are applicable to the study of streams in the Pacific Northwest:

1. The duBoys-type relationship assumes there is a critical shear stress where

$Tcr = \alpha d_{er} S$,

$\alpha$ = the specific weight of water,

$d_{cr}$ = depth of water,

$S$ = slope of water.

When this shear stress is exceeded (i.e., when the water depth exceeds the critical water depth $d_{cr}$), sediment transport proceeds according to:

$$q_s = \chi (\alpha S)^2 d (d - d_{cr}),$$

where

$q_s$ = sediment transport of bedload per unit width of channel,

and

$\chi$ = an empirical coefficient.

The applicability of equations derived for sand-bedded rivers is limited for Pacific Northwest streams. The Meyer-Peter Muller formula, a modification of the duBoys shear stress relation, was developed for armored gravel-bedded rivers. The equation, in English terms, is as follows:

$$q_s = 1.606 \left[ 3.306 \left( \frac{Q_s}{Q} \right) \left( \frac{D_{90}^{1/6}}{n_s} \right) 3/2\ dS - 0.627 D_m \right] 3/2$$

$q_s$ = bedload transport (tons/day/ft width of channel),

$Q_s$ = discharge quantity determining bedload transport (cfs) function of $n_w$ and $n_m$,

$Q$ = total water discharge quantity (cfs),

$D_{90}$ = armor size (mm) as approximated by the size of sediment for which 90 percent of the material is finer,

$n_s$ = weighted Manning's "n" value for the streambed, a roughness value,

$d$ = depth of flow (ft),

$S$ = slope energy gradeline (estimated by water surface slope),

$D_m$ = effective size of bed material,

$n_w$ = sidewall roughness value,

$n_m$ = total channel roughness.

For the condition at which bed material just begins to move, $D_m$ is replaced by the individual particle size D,

$dS = 0.0001624\ D$,

or shear stress $\alpha$ dS = 0.0001624 D $\alpha$ where $\alpha$ = specific weight of water (62.4 lb/cu ft).

For another variation of the shear stress approach, *see* Kalinske (1947).

2. Schoklitsch (1930), instead of using depth as the limiting parameter, formulated an equation using a critical discharge (discharge = area x velocity). The equation can be stated as:

$$q_s = \chi'' S^k (q - q_{cr}),$$

where

$\chi''$ = a new sediment coefficient,

$q_{cr}$ = the water discharge at which material begins to move,

$q$ = discharge at a particular time.

3. Because the critical condition for sediment transport is difficult to determine, H. A. Einstein (1950) approached the problem statistically, assuming sediment transport is governed by the fluctuations in velocity rather than by the average velocity. The material moves slowly down the stream in a series of short hops and rests, and there is an active exchange of particles in the bed with those in the moving bedload. Einstein included the effect of different sizes and shapes of material, and that of small particles hiding behind larger ones in his statistical analysis.

$$\phi = \frac{qs}{s} \left(\frac{\gamma}{\gamma_s - \gamma}\right)^{1/2} \frac{1}{gD^3} \quad {}^{1/2}$$

$$\chi = \frac{\gamma s - \gamma}{\gamma} \quad \frac{D}{R_b{}^{1}}$$

Based on experiments, $\phi$ and $\chi$ were related as $0.465\ \phi = \exp\ (-0.391\ \chi)$.

$R_b{}^{1}$ = hydraulic radius of sediment grain on bed,

$\alpha$ s = specific weight of sediment,

$\alpha$ = specific weight of water,

g = gravitational constant ($9.8 \times 10^2$ cm/sec).

## Suspended Sediment Transport

Suspended sediment is supported by the fluid rather than by the channel bed, and is usually calculated in terms of concentration. The concentration of suspended sediment is largely dependent upon availability as well as the intensity of the flow, so it may be higher on the rising limb of a hydrograph (representing the beginning of a storm and a large amount of available sediment) than on the falling limb (representing the end of a storm when most sediment available for transport has been washed away). Thus, there is potential for variability in sediment concentrations even at equal discharges at the same location. The concentration at a point is also often a function of its height above the bed. If z = the height above the bed, when $z < 0.2$ of the total water depth, d, the concentration can be expressed as:

$$\frac{c_s}{1-c_s} = \frac{c_s\ (z_a)}{1-c_s\ (z_a)} \left(\frac{Z_g}{Z}\right)^{P_S} \quad \text{where } P_s = \frac{w}{\alpha k\ u_*}$$

when $Z > 0.2$ d, the concentration is

$$\frac{C_s}{1-C_s} = \frac{C_s\,(Za)}{1-C_s(Za)} \left(\frac{Zq}{Zb}\right)^{P_s} \exp \quad -Ps \left[\beta_1 \left(\frac{Z}{d} - \frac{Z_b}{d}\right)\right]$$

where

$W$ = settling velocity of the suspended particles,

$k$ = von Karman's constant, 0.4,

$Z_b$ = 0.2 d,

$u^*$ = shear velocity = $\sqrt{T/e}$,

$\beta_1, \alpha$ = constants,

and $Z_a$ is the top of the bedload layer, which can be estimated by 2D (Einstein 1950) or by a function of $Z_0$, a roughness parameter of the bed.

The volume of sediment can be calculated by integrating the sediment concentration over the depth of water.

## Total Load

The total load, or more correctly, the bed material load of a stream can be calculated by adding the values of bedload and suspended load as computed above. At low transport rates where most of the sediment moves in contact with the bed, the bedload approximates the total load sufficiently well (Graf 1971, White et al. 1975).

Bogardi (1958) and Laursen (1958) have formulated empirical total load equations to estimate the concentration of sediment. "Total load" is somewhat of a misnomer for these equations, however, since the actual sediment discharge is not computed directly.

Besides carrying material that is found within the bed and that is moved at certain discharges, streams can carry washloads. The latter are made of up grain sizes finer than most of the bed material and, hence, are rarely found in the bed. This, coupled with the fact that there is not a clear relation between flow and washload, has made attempts at analytical determination of washload difficult (Einstein 1950).

# APPENDIX C

## TABULAR SUMMARY OF THE LITERATURE CONCERNING WATER QUALITY CRITERIA AND SEDIMENTS

| Code<br>Letter/Number | | Subject Concerns |
|---|---|---|
| Suspended solids | A | Duration of sediment effects |
| | B | Suspended sediments and spawning redds |
| | C | Damage to postemergents |
| | D | Suspended solids criteria |
| | E | Model stream approach |
| Bed material | 1 | Relationship of fines to organisms |
| | 2 | Oxygen requirements |
| | 3 | Percentage of fines allowable |
| | 4 | Duration of sediment effects |
| | 5 | Modification of bed composition |
| | 6 | Approaches |

## SUSPENDED SOLIDS

| Author | Year | Topic | Code |
|---|---|---|---|
| Bjornn | 1974*a* | Amount of sediment allowed in stream = total allowable level minus present level. | D |
|  | 1974*b* | Suspended sediment at high concentration causes short-term insect drift. | A |
| Bjorn et al. | 1974 | Small amounts of sediment in limit areas cause limited impact. | A |
| Buck | 1956 | Production of spiny-ray fish in farm ponds:<br>< 25 ppm → 161.5 #/acre<br>25-100 ppm → 94 #/acre<br>> 100 ppm → 29.3 #/acre.<br>Tolerance varies by species. | D |
| Cairns | 1967 | Biological indicator approach on drainage basin scale. | E |
| Cederholm and Lestelle | 1973 | Postemergents may have damage to gills (clogging, clubbing) as a result of contact with suspended sediments. | C |
| Cooper | 1965 | Suspended sediment concentration must be very low over spawning redds. | B |
| Ellis | 1944 | Sufficient concentration of solids with hardness < 1 can cause excessive mucus production. | C |
| EIFAC | 1965 | < 25 ppm = no harmful effects; 80 to 400 ppm = good fisheries doubtful; > 400 ppm = only poor fisheries. | D |
| Gammon | 1970*a* | 80 mg/liter suspended solids above normal amount present decreased insect density 60%. | D |
|  | 1970*b* | At low concentrations, 90% of particle weight = 10 μ diameter. At high concentrations 50% of particle weight = 20 μ diameter. | D |
| Gessler | 1975*a* | Aquatic environments adjusted to individual sediment loads and were directly or indirectly dependent on them. | E |
|  | 1975*b* | Develop land management techniques to prevent erosion. | E |

## SUSPENDED SOLIDS

| Author | Year | Topic | Code |
|---|---|---|---|
| | 1975c | Enforce standards on small streams and large streams will indirectly benefit. | E |
| Gessler | 1976 | Model stream approach; combination of biological and geomorphic characteristics. | E |
| Moring and Lantz | 1974 | Detrimental effects of sediments usually short-term on most streams. | A |
| Rice et al. | 1975 | Statistical and analytical models approach; standards must include flow variations and stream performance characters concurrent with monitoring system. | E |
| Shapley and Bishop | 1965 | Streams with lower high flow:low flow ratios need less sediment load to make more or less lasting changes in bed composition. | E |
| Wedemeyer and Yasutake (unpublished) | | < 80 ppm recommended limit for total suspended and settleable solids, for warm and cold water fishes. | D |
| Wilson | 1957 | Set standards as a percentage increase above normal low flows. | D |
| Wurtz | 1966 | Classify streams and establish criteria by class/river basin. | E |

## BED MATERIAL

| Author | Year | Topic | Code |
|---|---|---|---|
| Alexander | 1976 | In trout habitat ruined by alluvial sand deposits, trout populations remain in good shape by shifting food base to annelid worms. | 1 |
| Bjornn et al. | 1974 | Stream with highest degree of imbeddedness and highest percentage of fines < 1/4 inch diameter had fewest benthic invertebrates, lowest species diversity, fewest drift insects, but no effect on steelhead populations. | 1 |
| Brusven et al. | 1974 | Gabion deflectors, log drop structures, and debris removal increased sediment transport and improved fish habitat. | 5 |
| Burner | 1956 | $\text{Redd size} \equiv \frac{1}{\text{gravel size}} \equiv \frac{1}{\text{gravel concentrations}}$ | 1 |
| Burns | 1972 | Percentage of increase in sediments < 0.8 mm<br>10.2 → 13.3% = no effect<br>16.4 → 22.1% = partial effect<br>20.1 → 33.3% = decreased biomass of all fish species. | 3 |
| Cederholm | 1972 | Recommends stream system improvements be based on multidisciplinary approach, including interactions of sociology, geology, hydrology, and biology. | 6 |
| Cederholm and Lestelle | 1973*a* | High silt levels can decrease preemergent survival; depends on species and life stage. | 1 |
|  | 1973*b* | Shifting and erosion can cause mortality. |  |
|  | 1973*c* | Salmon require good permeability and oxygen in redd; oxygen consumption varies with depth and life stage--maximum just before hatching. | 2 |
| Cordone and Kelley | 1961 | Damage to eggs, food supplies, or alevins occurs long before adult fish are harmed. | 1 |
| Doudoroff and Warren | 1962*a* | Dissolved oxygen < 3 mg/liter insufficient for salmonids and other sensitive species. | 2 |
|  | 1962*b* | Intragravel velocity must be high enough to deliver oxygen to redds. | 2 |
| EIFAC | 1965 | Salmon spawning grounds should be as free as possible of fines. | 1 |

## BED MATERIAL

| Author | Year | Topic | Code |
|---|---|---|---|
| Ellis | 1937 | 5 ppm oxygen critical or limiting level. | 2 |
| Gaufin | 1962 | Stonefly larvae require large oxygen supply; do not use sand and mud. | 2 |
| Hansen | 1973 | Sediment basins must be large to trap fines; can be used above redds. | 5 |
| Hunt | 1969 | Diversionary devices reduced silt bottoms by 70%, sand by 40%. Fish food biomass increased in treated sections. | 5 |
| Koski | 1966 | Fines < 3.327 mm detrimental to preemergent survival. | 1 |
| Martin | 1976 | Duration of sediment impact on bottom fauna short-term. | 1 |
| McNeil | 1963 | 5-8 mg/liter oxygen necessary in natural redds; survival best in area with best oxygen supply; oxygen supply controlled by permeability, B.O.D. | 2 |
| McNeil | 1964 | 15% fines maximum for successful spawning redds. | 1, 3 |
| McNeil and Ahnell | 1964*a* | 5 yr after logging, levels of fines in gravels normal. | 4 |
|  | 1964*b* | Percentage of fines $\leq 0.833 = \frac{1}{\text{permeability}}$. | 3 |
|  | 1964*c* | Good permeability = < 5%; poor = > 15%. | 3 |
| Merrill | 1951 | Following slash clearing, bottom returned to normal in < 1 yr. | 4 |
| Moring and Lantz | 1974 | Coho populations not affected by logging; cutthroat populations were. Suggest use of cutthroat as indicator species. | 1 |
| Orcutt et al. | 1968 | About 60% of spawning gravels sampled contained 1/2-inch to 4-inch gravel; few with large boulders or fine compacting gravel and silt. | 3 |
| Phillips | 1975 | Emergent survival:<br>coho - 96% control, 8% with 60% sand;<br>steelhead - 99% control, 18% with 70% sand. | 3 |

## BED MATERIAL

| Author | Year | Topic | Code |
|---|---|---|---|
| Rees | 1959 | Aquatic insect preferences:<br>Diptera - low velocity, sand bottom;<br>Coleoptera - moderate velocity, sand-gravel mixture;<br>Ephemoptera, Plecoptera, Tricoptera - high velocity, gravel bottoms. | 1 |
| Tagart | 1976 | < 20% fines = increased survival; > 20% fines = decreased survival (fines < 0.850 mm). | 3 |
| Saunders and Smith | 1965 | Brook trout found only in silt-free bottom areas; return when unsilted. | 1 |
| Sheridan and Wilke | 1966 | Three passes with "riffle sifter" decreased gravel < 3.3 mm by 40% to 70%. | 5 |
| Von Tumbling | 1969 | Entirely biological approach; four classifications of natural waters based on dissolved oxygen, oxygen saturation deficit, B.O.D., ammonium ion saprobity. | 6 |
| Wickett | 1959 | Specific grading curves for gravels according to use by fish. Develop machine to produce "good" gravels. | 5 |
| Addendum: | | | |
| Hall and Lantz | 1969 | Percent survival (egg deposition to emergence):<br>1-3 mm sediments: steelhead - 40%;<br>coho - 20%-30%;<br>less than 0.83 mm sediments: coho - 20%. | 1 |

# APPENDIX D

## ANNOTATED BIBLIOGRAPHY

Note: The abstracts listed in this bibliography were obtained from a variety of sources. Abbreviations following each citation indicate the individual source. Sources included:

| | |
|---|---|
| (BA) | Biological Abstracts |
| (EPA) | U.S. Environmental Protection Agency. 1975. Forest harvest-regeneration activities and protection of water quality. USEPA Region X, Seattle, Washington |
| (GS) | Gibbons, D. R., and E. O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. USDA Forest Serv., Gen. Tech. Rep. PNW-10. 145 pp. |
| (M) | Mortensen, D. G., B. P. Snyder, and E. O. Salo. 1976. An analysis of the literature on the effects of dredging on juvenile salmonids. Special report to the Department of the Navy, March 15, 1976. 37 pp. |
| (NTIS) | National Technical Information Service |
| (OR) | Original Abstract (author) |
| (WP) | Water Pollution Abstracts |

No abbreviations indicate abstract was written by authors of this literature survey.

## ANNOTATED BIBLIOGRAPHY

Aitken, W. W. 1936. The relation of soil erosion to stream improvement and fish life. J. For. 34(12):1059-1061. (GS)

The author notes that gradual changes in stream environment caused by erosion can bring about corresponding changes in fish fauna. Without erosion control, stream improvement devices are of little value since they cannot eliminate turbidity, siltation, and other conditions resulting from erosion that are deleterious to fish life.

Alderdice, D. F., W. P. Wickett, and J. R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. J. Fish. Res. Board Can. 15:229-250. (OR)

Eggs of the chum salmon (*Oncorhynchus keta*) were exposed to various constant levels of dissolved oxygen for a period of seven days. The procedure was repeated with fresh egg samples at various developmental stages. Temperatures were constant at 10°C from fertilization to hatching. Estimates of oxygen consumption uninhibited by low dissolved oxygen levels were obtained at various stages of egg development for whole eggs and also on the basis of the weight of larvae, excluding the yolk. Eggs were most sensitive to hypoxia between 100-200 Centigrade degree-days and compensated for reduced oxygen availability by reducing the oxygen demand and rate of development. Very low oxygen levels at early incubation stages resulted in the production of monstrosities. At about the time the circulatory system becomes functional the compensatory reduction in rate of growth under hypoxial conditions is reduced, the eggs no longer survive extreme hypoxial conditions. Eggs subjected to low dissolved oxygen levels just prior to hatching hatch prematurely at a rate dependent on the degree of hypoxia. The maximum premature hatching rate corresponded approximately with the median lethal oxygen level. Estimated median lethal levels rose slowly from fertilization to hatching. Oxygen consumption per egg rose from fertilization to hatching while the consumption per gram of larval tissue declined from a high to a low level at about the time of blastopore closure. Subsequently, a slight rise in the rate occurred up to a level which was more or less constant to hatching. "Critical" dissolved oxygen levels were calculated and they appear to define the oxygen level above which respiratory rate is unmodified by oxygen availability. Critical levels ranged from about 1 ppm in early stages to over 7 ppm shortly before hatching.

Alsonso, C. V., J. R. McHenry, and J. C. S. Hong. 1973. The influence of suspended sediment on the surface reaeration of uniform streams. Mississippi State Univ., Water Resources Res. Inst. 61 pp. (OR)

The surface reaeration of uniform streams, with and without sediments in suspension, has been studied in the laboratory.

This equation was then modified in order to account for the effect of suspended sediments on the surface reaeration of uniform sediment-laden streams. The new equation was substantiated by the experimental results, which indicate that the reaeration rate decreases as the average sediment concentration increases. The decrease was attributed to the dynamic influence of the suspended particles on the turbulent flow field.

Anderson, H. W. 1957. Relating sediment yield to watershed variables. Trans. Am. Geophys. Union 38(6):921-924. (OR)

The yield of sediment from watersheds depends upon three sets of variables: (1) inherent watershed characteristics such as geology and topography; (2) land use, condition of vegetation, and management and protective measures; and (3) nature of storms and streamflow which produce and transport sediment. Measured quantities of yield also depend on the sediment measuring device and on which fraction of total sediment yield is measured. The sources of variation in sediment yield between and within watersheds can be evaluated by study of the yield from many watersheds which have wide differences in variables affecting sediment yields. Such studies are useful to determine and evaluate the principal sources of sediment, to evaluate the probable effects of conservation programs on yield, and to provide criteria for design of reservoirs and channels. This paper summarizes some recent studies in which multiple regression analysis was used in relating sediment yield to watershed variables. The studies are discussed in the light of methods of selecting watersheds, data, variables, and functions; and the effects of neglected variables, errors in variables, and exclusion of nonsignificant variables.

Anderson, H. W. 1970. Principal components analysis of watershed variables affecting suspended sediment discharge after a major flood. Int. Assoc. Sci. Hydrol. 96:404-416. (OR)

Increases in the sediment discharge from 31 watersheds after two major floods in northern California were studied by principal components analysis. Eleven years of sediment data after the December 1955 flood and 3 years of data after the December 1964 flood in California were analyzed. Relative flood size was expressed as the deviation from average annual flood size, divided by the mean annual discharge. Nonlinearity was evaluated by studying the interactions between variables expressing watershed conditions. Topographic variables were calculated from slopes of primary streams, elevation distribution, and surface path lengths. Sediment discharge was calculated from measured suspended sediment concentration, using the flow duration-sediment method. Increased suspended sediment discharge for average flow duration occurred after each major flood. The first year after the December 1964 flood, sedimentation was as much as five times the pre-flood amount. Poor land use practices--specifically, placing logging roads adjacent to streams and temporary log storage areas (landings) in draws--was associated with greater increases in suspended sediment concentration after the floods. Increases in sediment discharges over pre-flood rates were generally less each successive year after each flood. Equations were developed to relate the rate of decline of the increases in sediment to year since the flood and to watershed condition.

Anderson, H. W. 1971. Relative contributions of sediment from source areas and transport processes. Pages 55-63 *in* James Morris, ed. Proc. Symposium--Forest Land Uses and Stream Environment. Ore. State Univ., Corvallis. (OR)

The paper reports new findings, offers a reanalysis of older studies, and summarizes pertinent results in the literature. Past land use, forest fires, road building, "poor logging," and conversion of steep lands to grass have increased sediment discharge by factors ranging from 1.24 to more than 4. Projected future use is expected to increase sediment production by a factor of 4, with 80 percent associated with roads and 20 percent with logging. Major floods have increased subsequent turbidity of streamflow by a factor of 2. The increases were greater in logged areas of watersheds where roads were next to streams and landings were in draws than in undisturbed watersheds. Most landslides were associated with road development, next most with logged areas, and least with undisturbed forest area. The number of turbid days in streamflow varied by a factor of 2.34 with differences in silt plus clay content of soils, by 8.55 with differences in erodibility, and by 4.3 with the percent of gravel. Further, these soil characteristics were predictable from geologic rock types. In a sample calculation, 89 percent of channel bedload became suspended load enroute downstream. Soil creep contributed 15 percent to total sediment discharge from watersheds; channel bank erosion contributed 54 to 55 percent.

Andrew, F. J., and G. H. Geen. 1960. Sockeye and pink salmon production in relation to proposed dams in the Fraser River system. Int. Pac. Sal. Fish. Comm., Bull. 11. 259 pp. (OR)

Extensive dam construction recently proposed for the Fraser River system would, on the basis of present knowledge, seriously deplete the sockeye and pink salmon populations. To contribute towards a better understanding of the complicated nature of problems that would be involved in preserving sockeye and pink salmon if dams were constructed in the Fraser River system, and to contribute towards the possible solution of these problems, this report presents a review of available information concerning methods of passing adult and juvenile salmon over dams, the possible effects of environmental changes on production of sockeye and pink salmon, and methods of artificially propagating these species. Efficient passage of adult salmon over dams would be a critical problem in the Fraser River system in view of the large numbers of fish involved and the known intolerance of many races to migratory delay. Because methods have not been developed for safely passing large numbers of seaward migrants over the proposed Fraser River dams, a significant proportion of these fish would be killed in passage over spillways and through turbines. Other obvious effects of dam construction, such as creation of reservoirs, inundation of spawning areas, and alternation of lake rearing areas would also seriously reduce productivity. The effects of subtle environmental changes, such as altered temperatures and discharges, are more difficult to evaluate but, in view of the sensitive relationship between the fish and their environment, such changes could have serious adverse effects on productivity. Maintenance of the delicately balanced environmental conditions to which Fraser River sockeye and pink salmon have become dependent appears to be a prerequisite for maximum production. Alteration of the natural environment, an inevitable consequence of dam construction, could result in seriously reduced production of Fraser River sockeye and pink salmon. On the basis of present knowledge, hatcheries, artificial spawning grounds, and other artificial production methods in the downriver area would not compensate for loss of natural upriver production of sockeye and pink salmon. Extensive basic and applied research in salmon biology and fish-power problems is not being undertaken but there is no justification for expecting early solutions to all of the particularly complex Fraser River fish-power problems.

Angino, E. E., and W. J. O'Brien. 1968. Effects of suspended material on water quality. Int. Assoc. Sci. Hydrol. 78:120-128. (OR)

It has been stated frequently that the suspended material in streams and reservoirs does affect water quality. This is obvious; little information, however, is available as to just what some of these effects are. This paper summarizes *some* of the effects that the suspended load has or may have on determining water quality. The suspended material contributes to turbidity, hardness, alkalinity, water color, affects photosynthetic activity, and may be harmful to some organisms. In obstructing the penetration of light it induces a reduction in photosynthetic activity and thus indirectly causes a change in the oxygen content of the stream. The suspended load may act as substrate for bacteria, fungi, and other microorganisms as well as influence the concentration of certain compounds by adsorption and/or absorption. Little is known of the mineralogic make up of the suspended load and how it really affects water quality. For example, study of the suspended load of rivers draining the Cretaceous chalk terrain of Western Kansas showed that at certain times of the year a large part of the load is calcite. At other times considerable amounts of quartz, clays, and organic debris make up the river load. The calcite was a clearly identified component in transported sediments of the Kansas River as much as 150 miles east of the eastern limit of Cretaceous outcrops. Considering the solubility of $CaCO_3$ and the saturation of river water relative to $CaCO_3$, any solution of the suspended calcite influences the Ca, Mg, pH, $HCO_3$ values for these streams and thereby stream hardness. It is probable that part of the $CaCO_3$ is present as a sol accounting for the extreme distance it is carried. A relatively constant K and Mg content suggests a possible positive control by exchange reactions with the clay-load of the streams. Similar affects on the $NO_3$, $PO_4$, and possible $SO_4$ concentration are to be expected from seasonal changes in the organic content of streams.

The direct effect of suspended solids on organisms, chemical quality, photosynthesis, temperature, and oxygen content is poorly understood. Presently we know few of the detailed mechanisms by which suspended material has any effect on the water quality of the water carrying it.

Anonymous. 1975. State of Wash., Water Quality Assessment Rep., Vol. 1. 48 pp.

Included are a summary of water quality criteria (including numerical values for turbidity) and discussions of water pollution problems as they apply to the State of Washington.

Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Comm. (ORSANCO). 1956. Aquatic life water quality criteria. Second Prog. Rep. Sewage Indust. Wastes 28(5):678-690. (OR)

To the best of our knowledge adequate data are not available on the amounts of inorganic materials which can be added to a stream without significant harm to its productive capacity. The direct effect of turbidity and suspended solids on fishes is not a satisfactory criterion, since it has been found that fish can withstand large concentrations of suspensoids without any harm. The real influence on fish populations is exerted indirectly through a reduction of the food supply.

Criteria for judging the amount of inorganic materials which may be added to a stream, therefore, should be based primarily on the effect on the productivity of the stream bottom rather than on the acute or direct effect on fishes. The deposition of materials on the beds of streams may also be detrimental to fish reproduction because it covers spawning areas, smothers eggs, or makes areas unsuitable for spawning activities.

Since there is a lack of exact information concerning the effects of suitable solids on fish food production, fish spawning, and phytoplankton production, no criteria on the amount of such material which may be added safely to a stream can be formulated at this time.

Au, D. W. K. 1972. Population dynamics of the coho salmon and its response to logging in three coastal streams. Ph.D. Dissertation. Ore. State Univ., Corvallis. 245 pp. (GS)

This study examines the ecology and dynamics of coho salmon (*Oncorhynchus kisutch*) in environments experimentally altered by logging. The objective was to evaluate processes that stabilize or regulate the populations.

Two small watersheds in Oregon's Coast Range were logged in 1966, one clear-cut, the other patch-cut. A third adjacent watershed was left uncut as a control. The influence of these treatments on the biology of the coho was assessed. Attention was concentrated on populations of the six-year classes 1963 to 1968.

The natural variability of streamflow-related conditions influencing both the magnitude and pattern of coho recruitment each year was increased in the logged watersheds. Peak flow during storms increased; intragravel dissolved oxygen levels decreased in the stream draining the clear-cut water watershed. These changes, however, were apparently within the range of variation that the coho naturally experience. Increased stream temperatures and mortalities, due to the logging effects, altered the post-recruitment life conditions of the coho in that stream but did not significantly affect the final smolt yield.

Adjustments in coho population size were largely accomplished by fall, resulting in stable and characteristic population levels in each stream. A stable smolt yield was a further result. These adjustments are accomplished through high mortality during the months of the first spring and summer. This mortality is likely density dependent and related to the territorial and agonistic behavior of the fish.

Growth, biomass, and net production varied greatly during each year. Seasonal changes in growth rate resulted in seasonal variations in biomass that were in contract to the stabilized trends of population number. The pattern of net production rate was also largely determined by the seasonal growth pattern, and like biomass, did not show a tendency to stabilize with time. It averaged 5 $g/m^2$ among the three streams for the period June 1 to April 15.

This study has shown that coho streams normally produce characteristic levels of smolt yield in spite of large natural variations in fry input and conditions for growth. The range of environmental variation for which this result holds may include short-term changes due to logging. However a normal population response to such a severe alteration as occurred on Needle Branch is very likely conditional upon a program that at least includes vigorous stream clearance, the restriction of additional mortality to early summer, when population adjustments are far from complete, and the encouragement of streamside vegetation. A streamside buffer strip of trees is an effective way of protecting aquatic resources.

Bachman, R. W. 1958. The ecology of four northern Idaho trout streams with reference to the influence of forest road construction. M.S. Thesis. Univ. Idaho, Moscow. 97 pp. (GS)

Physiochemical and biological measurements of four trout streams, one of which was being logged, were studied. Turbidity was found to increase during rapid runoff from storms or snowmelt. Sedimentation increased in both riffles and pools. Water temperatures, volume of flow, and water chemistry showed no change from the previous year. The relocation of stream channels away from road fills appeared to reduce the amount of eroded material entering the stream.

Bartsch, A. F. 1959. Settleable solids, turbidity, and light penetration as factors affecting water quality. Pages 118-127 *in* C. M. Tarzwell, ed. Trans. Second Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

A few water pollution control agencies have adopted specific criteria to protect fish and other aquatic life from settleable solids and turbidity. A general lack of information on the effects they produce has caused other agencies to forego establishing criteria at this time. While the individual elements can be examined separately, settleable solids, turbidity and light are so interrelated as to require additional discussion as a single factor affecting the environment.

Settleable solids include inorganic particles from soil erosion and various industrial operations as well as living and dead suspended organic matter of natural or man-influenced origin. Particles that settle on the bottom can destroy fish food organisms, interfere with successful hatching of fish eggs, obliterate otherwise suitable spawning areas and carry unstable organic matter to the bottom where undesirable decomposition products are formed. While suspended, particles in sufficient concentration or of sufficient hardness and size may directly injure fishes and fish food animals. Specific cases that exemplify some of these effects are described.

Suspended particles also affect the optical properties of water so as to create turbidity. By impairing light penetration, turbidity diminishes the thickness of the euphotic zone and this limits basic productivity. Rates of photosynthesis in relation to light extinction in a raw sewage stabilization pond and in the Ohio River near Cincinnati are discussed. Quantities of phytoplankton in clarified and turbid waters of the Missouri River are another expression of impairment of basic productivity by turbidity. Turbidity may also affect temperature relations. In sport fishing waters, turbidity limits the distance at which sport fish can see the lure and thus affects both the yield and attractiveness of fishing waters.

Bell, Milo. 1973. Fisheries handbook of engineering requirements and biological criteria. U.S. Army Eng. Div., Corps of Eng., Portland, Ore. (M)

A 34-chapter handbook outlining various engineering and biological criteria for use in design of facilities which may have a potential impact on the aquatic environment. Criteria set forth in this publication are compiled from many sources and are valuable for developing "workable limits" but may be subject to change under varying conditions.

Bjornn, T. C. 1968. Survival and emergence of trout and salmon fry in various gravel-sand mixtures. Pages 80-88 *in* Richard T. Myren, ed. Logging and salmon. Proc. Forum Am. Inst. Fish. Res. Biol., Alaska Dist., Juneau, Alaska. (GS)

The survival and emergence of steelhead trout and chinook salmon were tested in various mixture of gravel and sand in troughs with flow and gradient control. The emergence of swim-up steelhead trout fry placed in the troughs was reduced by large percentages of sand. Swim-up chinook salmon fry appeared to be more impeded by sand than were steelhead trout, but these results need to be verified because some sick fish were unknowingly included in the test samples. The survival from green egg to emergence of chinook salmon was relatively high (70-77 percent) in gravel with little or no sand but much reduced in gravel with 18 percent or more sand.

Bjornn, T. C. 1969. Embryo survival and emergence studies. Job. No. 5., Sal. Steelhead Invest., Project No. F-49-R-7. Annu. Completion Rep. Idaho Fish Game Dep. 11 pp. (OR)

The survival and emergence of steelhead trout (*Salmo gairdneri*) and chinook salmon (*Oncorhynchus tshawytscha*) in gravel with various amounts of granitic sand were tested in troughs with flow and gradient control. Chinook salmon fry readily emerged from gravel with less than 20 percent sand, experienced difficulty in 20-40 percent sand, and few emerged from more than 40 percent sand. Most steelhead trout fry emerged from gravel with up to 30 percent sand, half emerged with 50 percent sand and only 10 percent emerged with 55 percent sand.

Sand in spawning gravel also reduced the flow of water through the gravel and created lethal conditions of low oxygen or high waste concentrations that caused large mortalities in troughs with 20 percent or more sand and spring water. In tests with spring and creek water mixed (higher initial oxygen content) the mortalities were less than with only spring water.

Mortalities of 60-80 percent of chinook salmon and 40-60 percent of steelhead trout embryos may occur when sufficient sand is present to fill the gravel interstices (30-40 percent sand). High egg to emergent fry survival is desirable as fewer adults are needed to adequately seed a rearing area.

Bjornn, T. C., M. A. Brusven, M. Molnau, F. J. Watts, and R. L. Wallace. 1974. Sediment in streams and its effects on aquatic life. Idaho Water Resources Res. Inst., Moscow. 47 pp. (NTIS)

Natural streams were surveyed, laboratory experiments were conducted, and sediment was added to a natural stream from July 1972 to June 1974 to assess the temporal and spatial impact of granitic bedload sediment (<1/4 inch) on insect and fish populations, and on the capability of the streams to transport sediment. Juvenile chinook salmon and steelhead trout were not adversely affected during the summer when sediment comprised up to 52 percent of the substrate in riffles. Reduction of pool area or volume in a small stream resulted in a reduction in summer capacity for fish proportional to the percentage of pool area or volume lost. Winter capacity of experimental streams for age 0 steelhead trout and chinook salmon was reduced when the riffles were fully sedimented. Addition of sediment to riffles temporarily reduced insect species diversity indices, but no reduction in insect abundance was observed. The Meyer-Peter-Muller formula appears most applicable to estimate sediment transport capabilities of mountain streams in the Idaho batholith. Sediment transport during the summer, low flow period was negligible in the streams studied.

Brannon, E. L. 1965. The influence of physical factors on the development and weight of sockeye salmon embryos and alevins. Int. Pac. Sal. Fish. Comm., Prog. Rep. 12. 26 pp. (OR)

The effects of water velocity, daylight and dissolved oxygen on the development and weights of sockeye salmon embryos and alevins were investigated. Before hatching, embryos were unaffected by the range of velocities studied, but were affected by exposure to diffuse daylight and different levels of dissolved oxygen. After hatching, the weights of the alevins and their rates of weight gain were influenced by velocity and oxygen, and their mortality was influenced by high velocities, especially when exposed to diffuse daylight. The significance of the effects of the three factors on the ultimate survival of fry are discussed.

Branson, B. A., and D. L. Batch. 1972. Effects of strip mining on small stream fishes in east-central Kentucky, USA. Proc. Biol. Soc. Washington 84(59):507-517. (M)

In this study the authors observed the effects of siltation from strip mining on the fish populations of two streams.

Results show that fish are eliminated or forced to move downstream due to high turbidity and siltation. Benthic organisms were reduced in number and species by 90 percent and reproduction in darters and minnows was reduced.

Brett, J. R. 1958. Implications and assessments of environmental stress. Pages 69-83 *in* P. A. Larkin, ed. The investigation of fish-power problems. Proc. H. R. MacMillan Lectures in Fish., Univ. Brit. Columbia, Vancouver. (OR)

The thesis is presented that a working definition of stress is a state produced by any environmental factor which extends the normal adaptive responses of an animal, or which disturbs the normal functioning to such an extent that the chances of survival are significantly reduced.

Two major subdivisions of stress can be distinguished, discriminate and indiscriminate. The chief distinction separating these two is in the status of the surviving individuals.

Discriminate stress is measured simply by the percentage loss, being strictly a lethal stress not inflicting any particular handicap on the balance of the assailed population. Losses from predation or from a fishery fall in this category, which is the reason why a population such as the sockeye of the Fraser River can withstand an 80 percent loss, yet reproduce at a sustained high level.

For indiscriminate stress, four categories appear to embrace most of the conditions under which this form of stress acts, viz., lethal, limiting, inhibiting and loading. Either by direct loss or through measures of metabolism reflecting reduced performance, a measure of the stress can be ascertained. Since altered water conditions are likely to cause indiscriminate stress, any loss from hydro-electric or other industrial development can be considered suspect for serious consequences to the total population.

The establishing of norms is one of the prime research responsibilities, from which an estimate of stress may be derived, and the safe limits of environmental change determine. The tasks are many and inviting. The examination of stress and how it operates should provide greater insight in the investigation of fish-power problems.

Brinkhurst, R. O. 1962. The biology of the Tubificidae with special reference to pollution. Pages 57-65 *in* C. M. Tarzwell, ed. Trans. Third Semimar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

The title of this paper is a little ambitious in relation to our knowledge of the biology of the aquatic oligochaetes and of the Tubificidae in particular. The subject is reviewed, however, under three headings: the establishment of physical and chemical tolerance limits for individual species; the search for indicator species whose mere presence or absence can be used to categorize the water concerned; and detailed analyses of community structure, emphasizing identification to species. Our fragmentary knowledge under the first heading is reviewed, but few if any conclusions can be drawn as yet in view of the interaction of factors in nature, the variability of tolerance levels within the species in respect to different stages in the life cycle, and other complications. Under the second heading it is claimed that there is no such universal indicator organism available, certainly not in the Tubificidae. Finally, the pattern of species distribution in relation to known sources of pollution in British rivers is described, and the hope is expressed that detailed surveys along such lines will clarify this pattern and so render invertebrate surveys more complete and more useful as a diagnostic tool.

Brown, C. L., and R. Clark. 1968. Observations on dredging and dissolved oxygen in a tidal waterway. Water Resources Res. 4(6):1381-1384. (OR)

Evidence indicates that resuspension of oxidizable bottom sediments in a tidal waterway caused significant reductions in the dissolved oxygen (D.O.) concentration of the water. During dredging, D.O. was reduced between 16-83 percent below normal.

Brown, G. W. 1972. Logging and water quality in the Pacific Northwest. Pages 330-334 *in* Nat. Symposium Watersheds in Trans. Am. Water Res. Assoc. and Colorado State Univ., Ft. Collins, Colo. (EPA)

Discusses and compares recent studies that show that clearcut logging can significantly affect stream temperature, sediment and dissolved oxygen. Losses of nutrients occur but are low in magnitude and short in duration in the Pacific Northwest. The forest soils had high infiltration rates because of high porosity. Surface and surface erosion are not the dominant form of natural or unaccelerated erosion, these steep watersheds mass wasting predominates. Small streams generally are characterized by large fluctuations in discharge, sediment concentration, and temperatures, even under undisturbed conditions.

Brown, G. W. 1974. Forestry and water quality. School of For., Ore. State Univ., Corvallis, Ore. 74 pp. (OR)

The objective of this text is to illustrate the interaction between man and his activities in the forest, the hydrologic cycle, and the quality of water in forest streams.

A well-written section on erosion and sedimentation in forested watersheds is included. Topics include: the erosion process on forested lands, impact of land use on erosion and sedimentation, preventing erosion and sedimentation problems, sampling suspended sediment, and sampling and measuring turbidity.

Brown, G. W., and J. T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon Coast Range. Water Resources Res. 7(5): 1189-1198. (OR)

The impact of road construction, two patterns of clear-cut logging, and controlled slash burning on the suspended sediment yield and concentration from three small watersheds in the Oregon Coast Range was studied for 11 years. Sediment production was doubled after road construction but before logging in one watershed and was tripled after burning and clear-cutting of another watershed. Felling and yarding did not produce statistically significant changes in sediment concentration. Variation in the relation between sediment concentration and water discharge on small undisturbed streams was large. Conclusions about the significance of all but very large changes in sediment concentration are limited because of annual variation for a given watershed, variation between watersheds, and variation with stage at a given point.

Brusven, M. A., and K. V. Prather. 1974. Influence of stream sediments on distribution of macrobenthos. J. Entomol. Soc., Brit. Columbia 71:25-32. (OR)

Studies were conducted in the laboratory and field to determine the substrate relationships of five species of stream insects representing the orders Ephemeroptera, Plecoptera, Trichoptera and Diptera. Various combinations of pebble and sand were tested in the presence or absence of cobble. Substrates with cobble were generally preferred over substrates without cobble. The preference for cobble generally increased as the sediments around the cobble decreased in size. Substrates with unembedded cobble were slightly preferred over half-embedded cobble; completely embedded cobble in fine sand proved unacceptable to most species. Three types of substrate-distribution patterns are recognized; stream insects which inhabit substrate surface; interstices; and both substrate surfaces and interstices.

Brusven, M. A., F. J. Watts, R. Leudtke, and T. I. Kelley. 1974. A model design for physical and biotic rehabilitation of a silted stream. Idaho Water Resources Res. Inst., Moscow, Idaho. Completion Rep. 36 pp. (OR)

A methodology was developed for rehabilitating a silt-polluted stream and the biological impact of rehabilitation on the insect community was measured. Field work was conducted in the East Fork and main stem of Emerald Creek in northern Idaho.

The study involved natural field conditions and laboratory simulation. Six control sites were selected based on similarity of flow, substrate type and channel geometry. Sediment samples were tagged and monitored, hydraulic structures were constructed for modification, and changes in the aquatic insect community were studied in conjunction with physical changes in the streambed.

Instream alterations were effective for increasing sediment transport, thus improving insect and fish habitat. Other improved conditions included increased pool-riffle ratios and higher values of percent cobble.

Due to its hydrological cycle, Emerald Creek can flush large amounts of fine sediments per year. But until the source of pollution sediments is eliminated, excessive loading will occur.

Buck, H. D. 1956. Effects of turbidity on fish and fishing. Trans. N. Am. Wildl. Conf. 21:249-261. (OR)

1. At the end of two growing seasons, the average total weight of fish in clear farm ponds was approximately 1.7 times greater than in ponds of intermediate turbidity and approximately 5.5 times greater than in muddy ponds. Differences were due to faster growths by all species and to greater reproduction in clear ponds, particularly by bluegills and redear sunfish.

2. Of the 3 species used in farm ponds, largemouth bass were most affected by turbidity in both growth and reproduction. Redear sunfish appeared less retarded in growth than did bluegills during the first year, but the two sunfishes appeared equally restricted in both growth and reproduction during the second year.

3. Average volume of net plankton in surface waters of clear ponds during the 1954 growing season was 8 times greater than in ponds having intermediate turbidities; 12.8 times greater than in the most turbid ponds.

4. In hatchery ponds, high turbidities reduced growth and total yield of bass and bluegills but increased channel catfish production. Individual catfish grew faster in clear ponds, but muddy ponds yielded much greater total weights of channel catfish than either clear or intermediate ponds. This was due to a higher rate of survival.

5. The presence of carp caused reduced growth of bass and bluegills but ponds with carp produced greater yields of channel catfish and young bluegills than ponds without carp.

6. Sodium silicate proved effective in sustaining hatchery pond turbidities when introduced in suspension with finely divided clay.

7. Growths of largemouth bass, white crappies, and channel catfish were much slower in turbid Heyburn than in clear Upper Spavinaw reservoir, as well as in all other Oklahoma reservoirs of similar age and size.

8. Growth of flathead catfish was the most favorable of any Heyburn species studied, and it is apparently well adapted to the turbid environment.

9. The number of species, as well as individuals, of all scaled fishes was low in turbid Heyburn reservoir, apparently due to a lack of successful reproduction in the turbid waters and also to competition from the better adapted catfishes.

10. Extreme scarcity of forage species, particularly gizzard shad, limited growth and development of bass, crappies, and other carnivorous species at Heyburn.

11. Heyburn largemouth bass and white crappie populations exhibited unusual dominance by older individuals. This seemed to be due to successively smaller year classes as a result of increasing turbidities.

12. In 1954, the average volume of plankton in surface waters was 13.8 times greater in Upper Spavinaw than in Heyburn, and average volume from the 60-foot depth at the clear reservoir was greater than the combined total from surface, 15-foot depth, and 30-foot depth in the muddy reservoir. This contrast was less marked in 1955, possibly due to somewhat lower average turbidities at Heyburn.

13. The clear reservoir attracted more anglers, yielded greater returns per unit of fish effort, as well as more desirable species, and was immeasurably more appealing in the aesthetic sense.

Bullard, W. 1959. Watershed management-grazing, deforestation and roadbuilding. Pages 27-31 *in* E. F. Eldridge and J. N. Wilson, eds. Proc. Fifth Symposium--Pac. Northwest on Siltation--its source and effects on aquatic environment. (GS)

Sources of siltation and methods to control and correct it are discussed. An outline of factors to consider in watershed management for the control of erosion and subsequent siltation of streams is presented.

Bullard, W. E. Jr. 1965. Role of watershed management in the maintenance of suitable environments for aquatic life. Pages 265-269 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (GS)

Increased sedimentation of streams seems to be the most obvious effect of land use practices on the aquatic habitat. The addition of finer particles on the bottom gravels reduces the niches where many benthic organisms live. Perhaps the direct effects on eggs are among the most important. There is a smothering effect from silt coatings and a decreased permeability of the bottom gravels reducing the flow of water over the eggs. The turbidity resulting from the increase in suspended particles also reduces the light penetration and photosynthetic rate.

Not all sedimentation is a result of obvious operations such as mining and cultivation. Instances are on record in which the activity of ducks has reduced fish egg survival. Perhaps the trampling of stream banks by cattle may be far more important than is commonly recognized. Changes in the stream bank brought about by cattle or man-made channel changes may produce a cycle of changes which may be carried clear to the mouth of the stream. Usually, these changes are not desirable.

The feeling among the discussants seemed to be that, ideally for fish production, partial tree cover of the banks, something less than complete bank stabilization, and an increase in rainfall infiltration of the soil are all desirable goals along with reduction in siltation and turbidity. However, the attainment of such goals may affect the stream flow patterns and reduce the total amount of water reaching the stream. In more arid areas, grasses are more desirable than trees because they achieve stabilization of soil but do not lose as much water through transpiration.

In any case, the optimum conditions for fish production will have to be sacrificed in many instances for multiple uses of the surface waters. However, the general feeling was that many improvements could be made that would improve the waters for fish production and still incorporate multiple use.

Burgner, R. L. 1960. Spawning and growth of fish. Pages 33-39 *in* E. F. Eldridge, ed. Proc. Seventh Symposium on Water Poll. Res., Water Problems in Watersheds of the Northwest. U.S. Dep. Health, Educ., Welfare, Portland, Ore. (OR)

In summary, we can expect that there will be a certain conflict between stream management by the biologists and the activities of logging, mining, and road building. However, there is an excellent possibility that production in many natural streams can be greatly improved by controlling stability of the stream and by removing fine materials. If this can be done, it may be possible to log more economically and with less concern about damage to the streams. However, before we proceed, we need some pilot plant operations to test our procedures. The task ahead is actually experimentation in the field where the salmon spawn and die.

Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish Wildl. Serv., Fish. Bull. 52(61):97-110. (OR)

Eight-hundred and fifty salmon redds in the Columbia River watershed were examined. Characteristics examined included current velocities, bottom composition of spawning sites, and density of spawners.

1. Observations were made on a large number of chinook, silver, chum, and blueback salmon redds in the Columbia River watershed, and 850 redds were measured.

2. Normally, the female salmon constructs the redd, the male taking no part in this activity.

3. The redd is formed or excavated by the female turning on her side and making violent flexions of the body and tail. The boiling currents set up by this action disturb the gravel of the stream bed which is carried a short distance downstream to form the tailspill.

4. A typical redd is an excavation in the stream bottom, oval in shape, the greatest diameter being lengthwise with the current, and with a tailspill at the downstream end. The center of the redd is referred to as the pot and it is here that the bulk of the eggs is deposited.

5. Current velocities at spawning areas varied from less than 1 foot a second to 3.5 feet a second. Redds made in fast water were invariably long and narrow; those in quiet water had a broad oval shape.

6. The current in the pot of the redd flows slightly upstream, which favors safe deposition of the eggs in the gravel and is conducive to complete fertilization by the milt of the male salmon.

7. As the spawning progresses, the redd in a sense moves upstream by continued excavation of the upstream edge and filling in of the tailspill area.

8. In general, salmon chose areas of stream bed composed of gravel less than 6 inches in greatest diameter, with the size of the redd inversely proportioned to the size of gravel. Firmly cemented gravel was avoided though where there was some cementation, the size of the redd was inversely proportioned to the amount of cementation.

9. Percolation of water through the gravel appears to be a requisite of the redd site.

10. In general, salmon prefer areas of stream bottom relatively free of mud or silt for redd-making purposes. Silvers (*O. kisutch*) were the only salmon of the four species which constructed redds in areas of stream bottom containing up to 10 percent mud.

11. Average redd size for the various salmon is as follows: Summer and fall chinook, 6.1 square yards; spring chinook, 3.9 square yards; silver, 3.4 square yards; chum, 2.7 square yards; and blueback, 2.1 square yards.

12. Few redds of any species were made side by side. For the most part, nests were either up or downstream from each other so that they would form diagonal rows across the stream.

13. The tendency of female salmon to prevent other females from getting too close resulted in inter-redd space approximately three times the size of the redd.

14. By dividing the area suitable for spawning in a given stream by four times the average redd area, a conservative estimate will be obtained of the number of salmon that may satisfactorily spawn in the stream.

Burns, J. W. 1970. Spawning bed sedimentation studies in northern California streams. Calif. Fish Game 56(4):253-270. (OR)

Changes in the size composition of spawning bed materials in six coastal streams were monitored for three years to determine the effects of logging on the habitat of silver salmon (*Oncorhynchus kisutch*) and trout (*Salmo gairdnerii gairdnerii* and *S. clarkii clarkii*). Four test streams were sampled before, during and after logging. Two streams in unlogged watersheds and the undisturbed upstream section of one test stream served as controls. A variety of stream types in second-growth and old-growth forests was selected for observation.

Spawning bed composition in the four test streams changed after logging, roughly in proportion to the amount of streambank disturbance. The heaviest sedimentation occurred when bulldozers operated in narrow stream channels having pebble bottoms. In a larger stream with a cobble and boulder bottom, bulldozer operations in the channel did not increase sedimentation greatly. Sustained logging and road construction kept sediment levels high in one stream for several years. Sedimentation was greatest during periods of road construction near streams and removal of debris from streams, confirming the need for special measures to minimize erosion during such operations. Control streams changed little in spawning bed composition during the three years.

Burns, J. W. 1972. Some effects of logging and associated road construction on northern California streams. Trans. Am. Fish. Soc. 101(1):1-17. (OR)

The effects of logging and associated road construction on four California trout and salmon streams were investigated from 1966 through 1969. This study included measurements of streambed sedimentation, water quality, fish food abundance, and stream nursery capacity. Logging was found to be compatible with anadromous fish production when adequate attention was given to stream protection and channel clearance. The carrying capacities for juvenile salmonids of some stream sections were increased when high temperatures, low dissolved oxygen concentrations, and adverse sedimentation did not accompany the logging. Extensive use of bulldozers on steep slopes for road building and in stream channels during debris removal caused excessive streambed sedimentation in narrow streams. Sustained logging prolonged adverse conditions in one stream and delayed stream recovery. Other aspects of logging on anadromous fish production on the Pacific Coast are discussed.

Busch, A. W. 1968. A suggested approach to the problem of water quality standards. Pages 458-461 *in* Indust. Waste Conf. I., 23rd Proc., Eng. Ext. Series 132. Purdue Univ., Lafayette, Indiana. (OR)

The use of the word standards in preference to criteria is chosen for this discussion in concurrence with the practice of other writers on the subject. The key element in the definition of standard is the phrase "established by an authority" where authority is in turn used in its legalistic rather than its expertise sense.

The following remarks are intended to point out the equity limitations of legislated standards, to suggest an alternate approach (primarily in practice), and then to examine how this approach differs from actuality and reality.

The philosophy behind this proposal is that accelerated pollution abatement efforts must be implemented and that while the "perfect" solution does not exist, better ones will be found. In the meanwhile, our present technological capability should be used in the most enlightened fashion possible without taking refuge in standards or in long lived studies to set standards. Broad based legislation is proposed which would encourage immediate action or a flexible approach without the rigidity of standards.

Cairns, J. Jr. 1962. The environmental requirements of freshwater protozoa. Pages 48-52 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent. (OR)

Although free-living Protozoa have a cosmopolitan distribution, a particular species will occur only where the appropriate environmental conditions exist. Since the environment changes constantly, a constant replacement of the component species of a protozoan population is a normal event. An examination of protozoan populations from 202 areas, classified as healthy or semi-healthy according to the system of Patrick (1949), in rivers and streams of the United States and other parts of the world resulted in identification of nearly 1200 species. Approximately 75 percent of these species occurred in three or fewer areas, or less than 1.6 percent, of the areas sampled. Of the 25 percent that occurred four or more times, only 20 species were found in 25 percent of the areas studied. For those species with saprobian designation, some sampling areas had excellent agreement in composition, although the greater number did not. An association matrix was made for the 20 most common species. A Chi square test of significance was run on the 190 possible associations of species pairs, and of these, 44 pairs occurred together more frequently than would be expected from chance alone at the 5 percent level of confidence. The data indicated that associations of three or more species also existed. Three main facts were noted in the course of the analysis: (1) pairs or larger groups of associated species always had virtually identical ranges of environmental conditions; (2) these species always tolerated rather broad ranges of environmental conditions; and (3) having identical ranges of tolerance to the chemical and physical environment does not insure that species will be associated more often than would happen by chance alone.

Due to the relatively low number of associated species and the broad range of tolerance of these species to the chemical and physical environment, it is evident that the best criterion for evaluation of the degree to which the requirements of protozoan populations are being met is the diversity of species within these populations. Since Protozoa are part of a larger aquatic community, the entire aquatic flora and fauna should first be evaluated and the structure and diversity of the protozoan population analyzed both as a unit and in terms of its relationship to the structure of the larger community of which it is a part.

Cairns, J. Jr. 1967. Suspended solids standards for the protection of aquatic organisms. Pages 16-27 *in* Indust. Waste Conf. I., 22nd Proc. (OR)

The literature indicates that discharge of particulate matter into a body of water may cause damage both while in suspension and after settling on the bed. Large amounts of naturally occurring particulate matter are not uncommon in many bodies of water and do not appear to endanger (and may even favor) the development of many species. It is also evident that the "normal" suspended solids concentrations of a particular stream or lake vary considerably. In addition, the response of aquatic organisms to a particular concentration will be affected by the stage in the life cycle, length of exposure, condition or health of the exposed organisms, presence of other toxic materials, quality of suspended material, etc. Since aquatic organisms survive (or at least enough survive to perpetuate the species) temporary exposure to rather high concentrations of suspended solids, it seems best to relate suspended solids standards to the variations and conditions to which the aquatic species have become adjusted. This would, of course, mean than the standards would be based on stream conditions rather than fixed arbitrary standards. Since stream flow and other characteristics vary from day to day this would require both continual monitoring of the water quality of each basin with appropriate information feedback to those using the stream.

Cairns, J. C. Jr., G. R. Lanza, and B. C. Parker. 1972. Pollution related structural and functional changes in aquatic communities with emphasis on freshwater Algae and Protozoa. Proc. Acad. Natur. Sci., Philadelphia 124:79-127. (OR)

The past and present tendency to ignore or minimize the importance of aquatic microbial communities when assessing the effects of pollution is clearly irrational. Microbial communities are not haphazard aggregations of species thrown together by the whims of nature but rather structured communities with numerous interlocking cause-effect pathways. It is evident that the requirements of microbial species and communities are as complex or nearly as complex as those of taxonomically higher organisms and that disruption of these communities by pollution can affect the entire aquatic food web. We urge that all environmental impact studies of aquatic ecosystems include an evaluation of the effects of pollution upon these communities and that standards be developed to protect them as well as fish and other organisms.

Cairns, J. Jr., K. L. Dickson, and Guy Lanza. 1973. Rapid biological monitoring system for determining aquatic community structure in receiving systems. Pages 148-163 *in* Biological Methods for the Assessment of Water Quality, ASTM STP 528. Am. Soc. Testing Mats. (OR)

Biological monitoring plays an important role in a pollution monitoring program providing information not available through conventional physical and chemical monitoring. The saprobic system and the use of structural and functional changes in aquatic communities are two approaches utilized in assessing the effect of pollutants on aquatic communities. The feedback of information from conventional instream biological monitoring has been too slow for the most effective management of an aquatic system. Two rapid biological monitoring systems (the Sequential Comparison Index, and an automated community structure analysis using laser holography) have been developed to increase the speed of data collection and data analysis.

California State Water Resources Control Board. 1963. Water quality criteria, Second ed. J. E. McKee and H. W. Wolf, eds. Publ. No. 3-A. 548 pp. (M)

This report is a survey and evaluation of the literature and compendium of data on water quality criteria. Conclusions and recommendations are presented on various topics which include water quality criteria of state and interstate agencies; judicial expression; quality criteria for the major beneficial uses of water; potential and biological pollutants; radioactivity; pesticides and surface active agents.

California State Water Resources Control Board. 1973. A method for regulating timber harvest and road construction activity for water quality protection in northern California. Vol. 1, Procedures and Methods. Vol. 2, Review of Problem and Annotated Bibiolgraphy., Publ. No. 50. Report compiled by Jones and Stokes Assoc. Inc. (OR)

This chapter defines major water quality problems in California, identifies information needed to assess and control water quality, and identifies wastewater treatment and reclamation technology needs. Legal, economic and institutional problems relating to water resources control in California are also described briefly.

Cederholm, C. J., and L. C. Lestelle. 1974. Observations on the effects of landslide siltation on salmon and trout resources of the Clearwater River, Jefferson County, Washington, 1972-73. Univ. Wash., Fish. Res. Inst., Final Rep. FRI-UW-7404. 89 pp. (OR)

Field investigation of the effects of logging operation-induced landslides on the composition of salmonid spawning gravel, stability of the streambed, concentrations of suspended sediment, populations of fish, and abundance of benthic fauna in Stequaleho Creek and the Clearwater River were carried out during 1972-73.

In Stequaleho Creek and the Clearwater River those gravel areas suitable for spawning downstream of the landslides were found to have significantly greater percentages of the less than 3.36 mm and 0.841 mm fines that the upstream control gravels. However, a high degree of gravel flushing since the landslides was evidenced by the relatively low levels in Stequaleho Creek. Cutthroat trout eggs planted in landslide-affected and -unaffected parts of Stequaleho Creek showed no difference in intragravel survival from eyed egg to hatch. Cross-sectional surveys of the lower Stequaleho streambed detected general streambed instability which may or may not be man-caused. Suspended sediment samples taken from various tributaries in the winter of 1971-72 showed Stequaleho Creek to have the highest sediment levels in most cases. The Yahoo Lake landslide caused additional turbidity in lower Stequaleho Creek occasionally during the summer of 1972.

Juvenile coho salmon and steelhead trout rearing densities were small in lower Stequaleho Creek when compared to densities in the upper Clearwater River during the summer of 1972. Resident cutthroat trout are quite numerous in upper Stequaleho Creek.

The populations of benthic organisms were significantly (1 percent level) lower in landslide-affected areas of Stequaleho Creek compared to landslide-unaffected areas. However, no significant difference (1 percent or 5 percent levels) existed for the Clearwater River above and below the mouth of Stequaleho Creek. When all stations were considered together, strong inverse correlation (June, $r = -0.85$; July and August, $r = -0.95$) was found between mean numbers of total insects per square foot per station and the percentage of sediment less than 0.841 mm in diameter, implying a reduction in the available living space for benthic organisms.

Chandler, D. C. 1942. Limnological studies of western Lake Erie. II. Light penetration and its relation to turbidity. Ecology 23(1):41-52. (M)

The present report is concerned with variations in turbidity of the waters of western Lake Erie and the effect of these variations on the depth to which 1 percent of the surface light penetrates. In this investigation year-round observations were made of: (1) turbidity, (2) light penetration, (3) amount of organic and inorganic suspended matter, and (4) quantity of phytoplankton. The study extended from September 1939 through October 1940, during which time several observations were made each month.

Chapman, D. W. 1962. Effects of logging upon fish resources of the West Coast. J. For. 60(8):533-537. (GS)

The author reviews the effects of logging on fish. It was found that after logging:

1) stream runoff was increased and as a result of heavy runoff gravel shifting occurred;

2) summer temperatures increased and winter temperatures decreased;

3) chemical quality of water deteriorated;

4) sediment increased;

5) stream energy source was disrupted; and

6) barriers to fish migration were left.

A good bibliography is included.

Chapman, D. W. 1963. Physical and biological effects of forest practices upon stream ecology. Pages 321-330 *in* Symposium--Forest Watershed Management. (EPA)

The report reviewed and discussed changes induced by land treatments on the aquatic ecosystem and their effect on stream ecology.

The effects of logging or other land treatment on fish cannot be determined by single-factor analysis, and consideration of the whole stream ecosystem is essential.

Chapman, D. W., and T. C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and eating. Pages 153-176 *in* T. G. Northcote, ed. Symposium on Salmon and Trout in Streams. Univ. Brit. Columbia, Vancouver. (OR)

Autecology of fish distributions is treated with particular attention to behavior of young chinook salmon and steelhead trout in Idaho streams. Behavior of other fish species and races is examined and discussed.

In the warmer months young chinook salmon and steelhead trout are associated with velocities and depths in proportion to body size, shifting to faster and deeper waters as body growth occurs. Interaction for space between species is minimal because of differing times of fry emergence. Distribution close to high-velocity water is food-related and density is socially-controlled with the greatest distributional role of social behavior played among fish of near-equal size. During the day the fish remain in a small home area, then settle at night to the bottom, generally after moving inshore.

Beginning in September many young steelhead and chinook salmon move downstream from tributaries to over-winter in larger streams, often living in the stream substrate. Most fish disappear into the substrate at temperatures below about 5°C, and winter cover is important in holding over-wintering fish.

Distributional behavior of young salmon and steelhead in the warmer months is similar to that of several other salmonid species. Winter hiding behavior is common in stream salmonids, often preceded by downstream movement in the fall. Return upstream movements in stream often occur. Such behavior in the colder months is probably directly related to water temperature.

Chutter, F. M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia 34(1):57-76. (OR)

Most of the literature concerned with the effects of silt and sand on the invertebrate fauna of streams and rivers has described changes taking place when biotopes are completely smothered by silt and sand. In few of these studies were the kinds of animals found recorded. There have been few studies of the effect of silt and sand on individual species. The invertebrate fauna of two biotopes in the streams and rivers of the Vaal River system, South Africa, changed with the amount of silt and sand in the watercourses. Where there were large amounts of silt and sand the variety of animals recorded from the stones in current biotopes was reduced, but the density of the fauna as a whole did not change. However the density of many groups of animals was affected. Some of the animals adversely affected by silt and sand appeared in large numbers below impoundments in which silt and sand would settle. In the sediment biotopes the summer density of the fauna was lowest where there was a lot of silt and sand. Large amounts of silt and sand were associated with large summer declines in the surface dwelling animals as a proportion of the whole sediment fauna. Differences between the summer proportions of surface dwelling forms in fine and coarse sediments were due to faunal differences. Sediments were not studied below impoundments.

It is concluded that there may be considerable changes in the composition of the stones in current fauna due to silt and sand without the biotope being smothered, and that increases in the amount of silt and sand in river beds lead to increased instability of the sediments, which adversely affects their fauna.

Clarke, F. E. 1967. What do we really know about stream quality criteria and standards? Water Quality Criteria, ASTM STP 416. Am. Soc. Testing Mats. Pp. 100-111. (OR)

Generally speaking, quality standards for streams are aimed at insuring maximum practicable utility of water resources for all intended users. Thus, the basic criterion in setting stream quality standards has been to insure absence of those quality factors which are dangerous or otherwise objectionable to the users. Lack of accurate information on effects of many pollutants hinders standardization, as does inability to perform accurate analysis for certain pertinent water components. Even if one could analyze accurately and be sure of the quality he desires in a river, the complex interactions of flow, water composition, seasonal variations and aquatic processes would make it quite difficult to set a single quantitative standard for any quality parameter. In some cases, efforts to reduce pollution are opposed by almost immovable forces of nature and thus are impracticable, if not almost impossible. The proper approach to setting stream quality standards under these circumstances is to accept arbitrary limits or ranges for the most pertinent solutes, suspended materials, and aesthetic factors, while performing the data collection and research necessary to place standardization on a firmer basis.

Coble, O. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans. Am. Fish. Soc. 90:469-474. (OR)

Movement of gravel 10 inches below the surface of a streambed was indicated in areas where no logging disturbance was apparent. The survival of salmonid embryos in the gravel was related to the apparent velocity and dissolved oxygen content of subsurface water.

Colby, B. R. 1957. Relationship of unmeasured sediment discharge to mean velocity. Trans. Am. Geophys. Union 38(5):708-717. (OR)

Unmeasured sediment discharges were computed by subtracting the measured suspended sediment discharges at alluvial sections from total sediment discharges that had been either measured at nearby contracted sections or computed from the modified Einstein procedure. Average curves show a general increase of unmeasured sediment discharge per foot of stream width as a function of about the third power of the mean velocity. At constant mean velocity the unmeasured sediment discharge per foot of width generally increases with concentration, especially with suspended sands concentration adjusted for depth of stream. Such adjusted concentrations of suspended sands seems to be reasonably good measures of the availability of sands. This availability is the relative rate of transport of sands for a given condition of flow and is related to particle sizes and cohesiveness of sediments of the stream bed and banks. Relationships of unmeasured sediment discharge to mean velocity and to concentration can be applied successfully in several kinds of sediment computations.

Colby, B. R. 1964a. Discharge of sands and mean-velocity relationships in sand-bed streams. USGS Prof. Pap. 462-A. 47 pp. (OR)

Graphs based on the empirical relationships of discharge of sands to major variables were prepared for a wide range of velocity, depth, water temperature, and concentration of fine sediment; they provide a method for quickly approximating the discharge of sands in sand-bed streams. In spite of many inaccuracies in the available data and uncertainties in the graphs, about 75 percent of the sand discharges that were used to define the relationships were less than twice or more than half of the discharges that were computed from the graphs of average relationship.

The agreement of computed and observed discharges of sands for sediment stations whose records were not used to define the graphs seemed to be about as good as that for stations whose records were used.

Colby, B. R. 1964b. Practical computations of bed-material discharge. ASCE, J. Hydraul. Div. 90(HY2):217-246. (OR)

At least five alternative measures of fluid forces or fluid velocities may have usually dominant effects on the discharge of bed-material in a sand-bed stream. Interrelationships among most of these measures vary widely with changes in the resistance to flow. Approximately defined average relationships between discharge of bed-material per foot of stream width and each of four usually dominant measures (mean velocity, stream power, and two forms of effective shear on the bed sediment) are shown graphically as possible bases for practical computations of bed-material discharge. Such usually secondary factors as depth of flow, particle size of the bed sediment, water temperature, and concentration of fine sediment affect each defined relationship, generally by different amounts.

Colby, B. R., and D. W. Hubbell. 1961. Simplified method for computing total sediment discharge with the Modified Einstein Procedure. USGS Water Supply Pap., 1593. 17 pp. (OR)

A procedure was presented in 1950 by H. A. Einstein for computing the total discharge of sediment particles of sizes that are in appreciable quantities in the stream bed. This procedure was modified by the U.S. Geological Survey and adapted to computing the total sediment discharge of a stream on the basis of samples of bed sediment, depth-integrated samples of suspended sediment, streamflow measurements and water temperature. This paper gives simplified methods for computing total sediment discharge by the modified Einstein procedure. Each of four nomographs appreciably simplifies a major step in the computations. Within the stated limitations, use of the nomographs introduces much less error than is present in either the basic data or the theories on which the computations of total sediment discharge are based. The results are nearly as accurate mathematically as those that could be obtained from the longer and more complex arithmetic and algebraic computations of the Einstein procedure.

Committee on Water Quality Criteria. 1972. Water quality criteria 1972. Environmental Studies Board, Nat. Acad. Sci., Nat. Acad. Eng., Wash., D.C. 594 pp. (M)

A report written for the U.S. Environmental Protection Agency concerning various aspects of water quality. This material is organized into six sections:

1. Recreation and Aesthetics,
2. Public Water Supplies,
3. Freshwater Aquatic Life and Wildlife,
4. Marine Aquatic Life and Wildlife,
5. Agricultural Uses of Water, and
6. Industrial Water Supplies.

Each of the sections are thoroughly discussed and water quality standards and guidelines, as established by the National Academy of Sciences, National Academy of Engineering, are presented.

Cooper, A. C. 1959. Discussion of the effects of silt on survival of salmon eggs and larvae. Pages 18-22 *in* E. F. Eldridge and J. N. Wilson, eds. Proc. Fifth Symposium--Pacific Northwest on Siltation--Its Source and Effects on Aquatic Environment. U.S. Dep. Health, Educ., Welfare, Portland, Ore. (GS)

Surface flow over a smooth bed with a constant gradient showed intragravel flow lines nearly parallel with some interchange near the surface. Interchange in the top 1 foot of stratum was increased with the addition of large rocks, and downward interchange occurred when a pile of gravel was formed by a female salmon digging a redd.

Cooper, A. C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. Int. Pac. Sal. Fish. Comm., Bull. 18. 71 pp. (OR)

Results are presented of studies made to assess quantitatively the effects of sediment deposition upon and within salmon spawning beds on the survival of salmon eggs and alevin. Methods of determining the size of bed load materials that may be expected on a given portion of a stream bed are presented. Spawning gravel permeability is defined in terms of particle size grading, particle shape and gravel porosity. The velocity of fluid flow through the gravel is quantitatively related to the gravel permeability and the hydraulic gradient. Deposition of sediment either on the gravel surface or within the gravel is shown to reduce gravel permeability with consequent reduction in fluid flow and reduction in rate of survival of salmon eggs and alevin deposited in the gravel. Formulae are developed which relate time and silt size and concentration to the effect on gravel permeability, and examples of the consequent effect on survival of salmon eggs and alevin are presented. The results of the studies show the importance of preventing deposition of sediments on or within a salmon spawning bed.

Cooper, R. H., A. W. Peterson, and T. Blench. 1972. Critical review of sediment transport experiments. ASCE, J. Hydraul. Div. 98(HY1): 827-843. (OR)

Many of the formulas dealing with the transport of sediment in mobile bed channels are empirical or semiempirical in nature and have been based on the results of laboratory flume experiments. Where the experimental collections used to develop a formula cover only a narrow range of flow conditions, there exists a danger of errors resulting when the formula is extrapolated to practical engineering conditions. This danger is particularly severe in those cases where empiricism has been relied upon in determining both the mathematical form of the relation and the required numerical constants.

The present study is concerned with: (1) Describing the nature and scope of existing collections of data, considered individually and as a whole, and (2) comparing the scope of experimental conditions with conditions likely to be encountered in engineering practice. It is hoped that the results will point to gaps in existing experimental knowledge, limitations in the applicability of empirical formulas, and serve as a guide in the design of future experiments.

Cordone, A. J. 1956. Effects of logging on fish production. Calif. Fish Game, Inland Fish Admin., Rep. No. 56-7. 98 pp. (GS)

The material examined consisted of published and mimeographed literature, regulations and policies, and correspondence. No attempt was made to compile a complete bibliography. However, it is believed that the more important published and mimeographed literature was reviewed. The subject of pollution from sawdust and sulfite liquor wastes was not covered. The physical influences of logging on the environment were stressed, i.e., soil erosion, turbidity, sedimentation, fluctuating stream flows, etc. Material on direct effects of logging on fish life was rare, but papers concerning the foregoing factors were common. That these factors are interrelated with fish production is universally accepted.

The report is divided into three parts: (1) review of literature, (2) review of regulations and policies, and (3) list of literature not examined. The first part is presented in the form of an annotated bibliography. Direct quotes are employed as annotations whenever feasible. This eliminates some subjective interpretations. A brief summary of the surveyed material is presented at the end of the report.

Cordone, A. J., and D. E. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. Calif. Fish Game 47:189-228. (M)

This report discusses the effects of inorganic sediment on fishes; fish eggs and alevins; bottom organisms; aquatic plants; physical habitat and populations. Discussion of sediment standards and research was included.

Cordone, A. J., and S. Pennoyer. 1960. Notes on silt pollution in the Truckee River Drainage. Calif. Dep. Fish Game, Inland Fish. Admin., Rep. No. 60-14. 25 pp. (GS)

Silt from a gravel washing plant drastically reduced the populations of bottom organisms immediately below the outfall and as far as 10 miles downstream at Cold Creek and Truckee River, California.

Cottam, C., and C. M. Tarzwell. 1959. Research for the establishment of water quality criteria for aquatic life. Pages 226-232 *in* C. M. Tarzwell, ed. Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

The main beneficial uses of our waters are: domestic, agricultural, aquacultural, industrial, recreational, aesthetic, navigation and power. To maintain or restore the suitability of our waters for these stated purposes, our first task is to determine the water quality characteristics which are required for each of these uses for we cannot effecively measure pollution, determine needed correction, or evaluate control measures until we have established these essential characteristics. In this paper attention will be directed toward research needs for the establishment of water quality criteria for aquatic life.

Cummins, K. W. 1967. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. Am. Midland Naturalist 67(2):477-504. (OR)

A consideration of a large number of procedures for the collection and analysis of benthic samples, with particular emphasis on stream investigations and the importance of substrate particle size as a common denominator in benthic ecology, reveals that only certain techniques are suitable.

Although either systematic or stratified random samplings are appropriate for faunal surveys, the careful selection of sample sites in single-species studies can provide maximum information per unit sampling effort. In order to adequately describe the micro-distribution of benthic organisms, investigations must be conducted on a year-round basis. Only bottom samplers, such as the core-type, which retain the entire sediment sample for analysis are desirable. Measurements of current velocity should be made close to the substrate-water interface. The removal of the fauna by elutriation and hand sorting allows for further physical and chemical analyses. Physical analysis of stream sediments can be accomplished through the decantation of silt and clay followed by dry sieving of the coarser material. In addition, a new photographic technique for substrate analysis, described in detail, can provide information on the surface sediments. Indications of the organic content of sediments can be obtained by the dry combustion carbon train method or, when clay content is low, from loss of weight on ignition values. However, new techniques are called for, especially those directed toward the food habits of particular species. The Wentworth classification, modified to include a gravel category, should be followed, and the size classes converted to the *phi* scale in graphic presentations of sediment data.

Cummins, K. W., and G. H. Lauff. 1969. The influence of substrate particle size on the microdistribution of stream macrobenthos. Hydrobiologia 34:45-181. (OR)

Substrate microhabitat preferences of ten species of benthic macroinvertebrates were investigated in a laboratory flowing water system and compared with preliminary field data. Eight particle size categories of both silted and non-silted substrates were tested in the laboratory.

The correspondence between field and laboratory data indicated primary microhabitat selection on the basis of substrate particle size by the stonefly *Perlesta placida,* the riffle beetle *Stenelmis crenata* and the caddisflies *Pycnopsyche guttifer* and *P. lepida.* Broad substrate responses in the laboratory and lack of correspondence with field data indicated a secondary importance of substrate particle size in microhabitat selection by the pulmonate snail *Helisoma anceps,* the caddisfly *Helicopsyche borealis*, the cranefly *Tipula caloptera*, the alderfly *Sialis vagans* and the mayflies *Caenis latipennis* and *Ephemera simulans.*

Silting had minor effects on substrate selection patterns in all species tested except *Caenis latipennis* and *Perlesta placida* in which it enhanced selection for the interstices of coarse sediments.

Curry, L. L. 1962. A survey of environmental requirements for the midge (Diptera: Tendipedidae). Pages 127-141 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

A brief history of the taxonomy and the limnological importance of the family is given. When possible, synonymy is given for the important species to enable the researcher to relate his data to that of different geographical regions. Interpretations of environmental requirements for the more common species of the family are based primarily on the Michigan fauna. Evaluations are made for the Holarctic, Neotropical, and Ethiopian realms, however, when these data are available. The environmental conditions considered are oxygen, carbon dioxide, sulfides, sulfites, acids, some organics, pH, temperature, fiber deposits, and siltation. These are considered with respect to midge populations in lothic and lentic environments, as well as in the littoral and profundal regions of freshwater lakes. The maximum conditions tolerable to midge populations in these environments are given when known. Several general conclusions are drawn from the study. Field work indicates that no group of midges can be regarded of pollutional indicator organisms per se. The species *Tendipes (T.) riparius* (Meigen) (=*Chironomus riparius* Meigen) and *T. (T.) tentans* (Fabricius) (=*Chironomus tentans* Fabricius) could be considered as such, however. Some species in the family are restricted either to a lentic or lotic environment. Others are known to inhabit both environments. In addition, a few species are able to adapt to the physical and chemical conditions imposed upon the organisms in the littoral and profundal regions of larger bodies of water. In general, the conditions discussed in this paper, when imposed upon the midge fauna, have a detrimental effect upon the population.

Dill, L. M. 1969. The sub-gravel behavior of Pacific salmon larvae. Pages 89-101 *in* T. G. Northcote, ed. Symposium on Salmon and Trout in Streams. Univ. Brit. Columbia, Vancouver. (OR)

Results of a study of the sub-gravel behavior of the coho salmon (*Oncorhynchus kisutch*) are compared with studies of other salmonid larvae. The present results were obtained through observation of the larvae or alevins in specially designed aquaria. The alevins moved about within the gravel prior to emergence, apparently as a result of phototaxes and rheotaxes, the direction of which varied with the age of the fish. For example, the response to light was initially negative, but changed to positive as the time of emergence approached. Lateral movements were similarly influenced by the current direction.

There was evidence that the alevins were spacing themselves out within the gravel, and that some interaction was taking place between them. The effects upon behavior of changes in burial density, burial depth, and gravel size were also explored. Several studies are suggested as logical and productive continuations of the present work, and their implications are discussed from both practical and theoretical standpoints.

Dill, L. M., and T. G. Northcote. 1970. Effects of gravel size, egg depth, and egg density on intragravel movement and emergence of coho salmon (*Oncorhynchus kisutch*) alevins. J. Fish. Res. Board Can. 27(7):1191-1199. (OR)

In experimental aquaria with large gravel (3.2-6.3 cm), vertical and lateral movements of coho salmon (*Oncorhynchus kisutch*) alevins were more extensive and area utilized per alevin was greater than in small gravel (1.9-3.2 cm). At low density (50 per aquarium) the alevins moved farther towards the inlet, but the mean area occupied per alevin was the same as that at high density (100 per aquarium). Burial depths tested (20 and 30 cm) had no significant effects on vertical or lateral movements or on area utilized per alevin. Alevin orientation in the gravel, survival to emergence, and timing of emergence were not affected by any of the environmental variables examined.

Doudoroff, P. 1957. Water quality requirements of fishes and effects of toxic substances. Pages 403-430 *in* M. E. Brown, ed. The Physiology of Fishes. Vol. 2, Behavior. Acad. Press, Inc., New York. (OR)

This chapter is an introduction to the physiological and toxicological principles of water quality appraisal relating to the requirements of fishes, and a guide to correct interpretation and application of basic data to be found in the voluminous pertinent literature. All of the essential information could not be included. Reference is made, however, to some useful literature reviews and compendia, as well as original sources of data.

Simple physical and chemical criteria of the suitability of waters for fish cannot be prescribed for general application, because the requirements of species vary greatly, and also because of the large number and the complex interaction of factors which together determine or can influence the quality of water. Arbitrary water quality standards and lists of unqualified critical or maximum tolerable concentrations of water pollutants which can be harmful to fish have been published repeatedly. Useful though these may appear to be, they actually are apt to be misleading more often than helpful, for they are based on fragmentary information and have been prepared without proper regard to unrefuted contradictory evidence. An intelligent approach to water quality and pollution problems relating to the complicated requirements of aquatic life involves careful consideration of all available pertinent data, in the light of general principles discussed herein.

A distinction must be made between tolerable environmental conditions determined experimentally in the laboratory and those conditions under which fish can be expected to occur and thrive in nature. In order to maintain themselves in their natural habitats, fish must be more or less active, they must find and capture food (competing effectively with other species), resist currents, escape enemies, grow, and reproduce successfully. Their ability merely to survive under unnatural experimental conditions requiring no sustained activity obviously is not a reliable indication that the quality of the medium is satisfactory.

It must be concluded that the present state of our knowledge and understanding of the water quality requirements of fishes is such that the suitability of any untried water must be judged chiefly with reference to limits or ranges of tolerance determined experimentally. Even these cannot be precisely defined without much qualification. One can only surmise what alterations of water quality will have no detrimental effects on populations of fishes in their natural environments. The lethality data presented in connection with the following discussion of the resistance of fish to various harmful agents should be viewed in the light of the foregoing considerations, and applied accordingly.

Doudoroff, P., and D. L. Shumway. 1967. Dissolved oxygen criteria for the protection of fish. Pages 13-19 *in* C. L. Cooper, ed. A Symposium on Water Quality Criteria to Protect Aquatic Life. Am. Fish. Soc. Spec. Publ., No. 4. (OR)

The rates of growth and embryonic development and the activity of fish can be limited by the supply of oxygen even when dissolved oxygen concentrations are near or above air-saturation levels. Yet, oxygen concentrations well below 3 mg/liter can be tolerated for long periods by the fish and fish embryos. Fishery biologists should decline, therefore, to specify any particular dissolved oxygen level as a minimal requirement of any fish population or as a proper standard of water quality until the necessary clear guidelines or explicit definitions of terms are provided by pollution-control agencies desiring such simple criteria. The dissolved oxygen level at which growth of fish is limited by the oxygen supply depends on the amount of food available, as well as other environmental factors such as temperature. No reduction of dissolved oxygen below natural levels probably is the only "standard" that would afford complete protection for fishery resources under all circumstances, but adoption of this standard for the regulation of waste disposal usually would be unrealistic and unnecessary. Any lower or less restrictive standards applicable over wide ranges of temperature probably should be expressed as oxygen concentrations (mg/liter) rather than as percentages of saturation. They should be designed to prevent, by limiting diurnal or other fluctuations of dissolved oxygen, frequent exposure of fish to nonlethal but very low dissolved oxygen levels even for periods of moderate duration. The choice of suitable criteria or standards probably should be based in part on bioenergetic considerations relating to fish growth and production rates, but it is not simply and entirely a biological problem, many considerations other than biological ones clearly being pertinent.

Doudoroff, P., and C. E. Warren. 1957. Biological indices of water pollution with special reference to fish populations. Pages 144-163 *in* C. M. Tarzwell, ed. Trans. of a Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

A genuine contribution to water pollution science can be made whenever the presence or relative abundance of living organisms of any kind can be shown to be a reliable index of something tangible that one may need to know in order fully to ascertain and understand the pollutional status of an aquatic environment. Widely distributed sessile or sedentary organisms should be the most useful indicators of past conditions. Unfortunately, the water quality requirements of most of the "indicator organisms" have never been thoroughly investigated, so that there is no real knowledge of specific factors which limit their distribution and abundance. If there are common sedentary organisms whose water quality requirements can be shown to correspond closely with those of valuable fish species, they are potentially useful indicators. At the present time, however, excepting instances of growth pollution, only fish themselves can be said to indicate reliably environmental conditions generally suitable or unsuitable for their existence.

Doudoroff, P., and C. E. Warren. 1962. Dissolved oxygen requirements of fishes. Pages 145-155 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

Dissolved oxygen concentration has been shown to influence markedly the maximum or active rates of oxygen consumption and the sustained swimming performance capabilities of fresh-water fishes at any given temperature. When food supply is unrestricted in laboratory tests, oxygen concentration influences likewise the rates of food consumption and of growth, and under extreme conditions, the gross efficiency of food conversion. The rates of embryonic and larval development, the size of larvae at the times of hatching and of completion of yolk absorption, and so the efficiency of yolk utilization, also are dependent on oxygen concentration. The effects of reduced concentrations on embryonic development vary not only with temperature, but also with the velocity of the water which determines the rate of delivery of oxygen to the chorion surfaces. Marked reductions of active rates of oxygen consumption by fish, of maximum sustained swimming speeds, and of rates of development, food consumption, and growth have been observed upon reduction of oxygen concentration to levels only slightly below the air-saturation level. The appetite and the growth rates of fish can be greatly impaired by wide diurnal fluctuation of oxygen concentration. The impairment occurs even when the arithmetic or geometric mean oxygen concentrations, i.e., the properly weighted means of the alternating low and high concentrations to which the fish are exposed, fall within the range of most favorable constant concentrations and the duration of daily exposure to low concentrations is only one-third or one-half of the 24-hour day. Abnormally high concentrations well above the air-saturation levels also can be inhibitory. Prompt avoidance reactions of fishes to reduced oxygen concentrations well above those that are lethal or cause obvious distress have been observed under experimental conditions.

The ecological significance of all the above observations made in the laboratory is not yet clear. Oxygen concentrations avoided under some experimental conditions may not be avoided likewise under natural conditions. Swimming speeds and developmental rates that are essential to survival and unimpaired success of fish in natural environments, as well as larval sizes that must be attained at the time of hatching or of complete yolk absorption are unknown, but presumably can be determined experimentally. The critical oxygen concentration for incipient impairment of growth under natural conditions probably depends on the availability of food, which may itself be the major factor limiting growth rates. This critical concentration may well depend also on the rate at which energy must be expended by the fish in seeking and capturing available food, while also escaping enemies, etc. The appetite of the fish or the activity that presumably is necessary for food procurement, or both, evidently must be reduced when available oxygen becomes insufficient for supporting all metabolic processes at normal levels. Accordingly, a satisfactory laboratory model for studies of the dissolved oxygen requirements of fish, directed toward reliable estimation of critical concentrations at which incipient impairment of growth would occur in a given natural environment, cannot be a very simple one. Evidently it must combine the food ration normally obtainable under favorable dissolved oxygen conditions in the natural environment with enforced activity approximately equivalent to the spontaneous and other activity that under the natural conditions would be essential for survival and normal feeding. This conclusion applies also to the study of other water-quality requirements of fishes.

Duchrow, R. M., and W. H. Everhart. 1971. Turbidity measurement. Trans. Am. Fish. Soc. 100(4):682-690. (OR)

A quick and reliable method of measurement is necessary to set standard limits on the amount of suspended sediment to be tolerated in streams near land-use operations. Turbidity measurements may be useful if a major portion of the total turbidity is contributed by settleable solids, if a relationship exists between turbidity readings and weight per unit of volume of suspended sediment, and if a reliable meter is available. Water with turbidity readings greater than one JTU (Jackson Turbidity Unit) is generally composed mostly of settleable solids unless distorted by color. Non-filterable and total dissolved solids contribute variable amounts of light penetration reduction. Percentage contribution to turbidity of settleable solids is highly variable from sample to sample and from station to station.

A high correlation exists between turbidity readings and weight for individual sediment types of suspension, but a poor relationship exists when sediment type is varied. Experiments conducted on the Hach model 2100, the Helige, and the Jackson Candle turbidimeters resulted in a highly significant difference ($a = 0.01$) between readings on the same sample of suspended sediment. Turbidity is a questionable measure of suspended solids in water. A more accurate index would be suspended solids measured gravimetrically.

Edington, J. R. 1969. The impact of logging on the ecology of two trout streams in north Idaho. M.S. Thesis. Univ. Idaho. 73 pp. (EPA)

The effects of logging on an experimental and control stream was studied for 11 years in northern Idaho. Clearcut and selective logging varied on each location. Impact on the stream ecology was noted early in the study, due mainly to road construction. A decline then a gradual increase to previous levels was noted for four orders of stream insects with the exception of the order Plecoptera which showed a decline in abundance due to siltation. There was no apparent effect on trout populations. The timing and methods of timber harvesting are credited for the moderate effects to the stream ecology.

European Inland Fisheries Advisory Commission. 1964. Water quality criteria for European freshwater fish. Report on finely divided solids and inland fisheries. Inland Fish. Advisory Comm. EIFAC Tech. Pap. (1):21 pp. (M)

This is the first of a series of reports on water quality criteria for European freshwater fish prepared for and approved by the European Inland Fisheries Advisory Commission. The background of the project is described and reasons for establishing water quality criteria for fish explained. This is followed by a literature survey of: the direct effects of solids in suspension on death or survival of fish, their growth, and resistance to disease; suspended solids and reproduction; effects on behavior; effect of food supply; and total effect of suspended solids on freshwater fisheries. Finally tentative water quality criteria are suggested.

Einstein, H. A. 1950. The bed-load function for sediment transportation in open channel flows. Soil Conser. Serv., Tech. Bull. No. 1026. (OR)

(1) A unified method of calculating the part of the sediment load in a alluvial stream that is responsible for maintaining the channel in equilibrium, namely, the bed-material load, is set forth.

(2) The relationship between the rate of transport of bed-material load, its size composition, and the flow discharge is called the bed-load function and is explained for the case of a channel in equilibrium.

(3) The first part of the calculation covers the hydraulic description of the flow for each discharge.

(4) The resulting equilibrium transport is divided into two parts: (a) the suspended load which includes all particles the weight of which is supported by the fluid flow, and which has been found to include all particles moving two diameters above the bed or higher; and (b) the bed load which includes all particles moving in the bed layer, a layer two diameters thick along the bed. The weight of all particles moving in the bed layer is supported by the bed as they are rolling or sliding along. On the basis of this definition, the thickness of the bed layer is different for the various grain sizes of a sediment mixture.

(5) The motion of bed-material load in suspension is described by the commonly accepted method based on the exchange theory of turbulent flow. The transport is integrated over a vertical.

(6) The description of the bed-load motion in the bed layer is the same for fine sand as for coarse particles which never go into suspension. The effect of varying ratios between the grain size and the laminar sublayer thickness must be allowed for and evaluated, however.

(7) A complete sample calculation for a reach of Big Sand Creek, Mississippi, demonstrates the practical application of the method and of its formulas and graphs.

Einstein, H. A., and M. A. Farouk. 1972. Einstein bed load function at high sediment rates. ASCE J. Hydraul. Div. 98(HY1):137-151. (OR)

A method is suggested which can be used to extend the applicability of bed-load calculations to the case of high sediment concentrations near the bed for near uniform bed material.

It is found that, by changing the von Karman coefficient equally in both the velocity and in the suspended sediment distributions, a reasonable solution is obtained for both flume experiments and river measurements. The changed $k$ value is predicted as a function of the dimensionless parameter $(\underline{v_{s35} D_{65}}/(q^{1/2} S_e^{1/2} v^{1/2})$.

Ellis, M. M. 1931. Some factors affecting the replacement of the commercial freshwater mussels. U.S. Dep. Commerce, Bur. Fish., Fishery Circ., 7. 10 pp. (OR)

Erosion silt is destroying a large portion of the mussel population in various streams by directly smothering the animals in localities where a thick deposit of mud is formed; by smothering young mussels even where the adults can maintain themselves; and by blanketing the sewage and other organic material which in turn produces an oxygen want that lowers the oxygen content of the water to the detriment of those species requiring well-aerated water. Very young mussels are particularly sensitive to the low oxygen tensions in the water.

Extensive and rapid reduction, amounting in many places almost to extermination, of the mussel fauna is to be expected if the erosion and pollution problems are not solved, in view of various improvements for navigation now existing or already authorized throughout the Mississippi, Ohio, and Tennesee drainages.

Ellis, M. M. 1936. Erosion silt as a factor in aquatic environments. Ecology 17(1):29-42. (M)

The paper discusses the effects of silt on the aquatic environment. Erosion silt alters aquatic environments, chiefly by screening out light, by changing heat radiation, by blanketing the stream bottom, and by retaining organic material and other substances which create unfavorable conditions at the bottom.

The present erosion silt loads of our inland streams have reduced the millionth intensity depth for light penetration from 15,000 mm to 34,000 mm or more, to 1,000 mm or less, the summer average for the Mississippi River above Alton, Illinois, being less than 500 mm.

Erosion silt in river water act chiefly as an opaque screen to all wave lengths of visible light but in very muddy waters a small difference was found favoring the transmission of scarlet-orange light.

Erosion silt alters the rate of temperature change in river waters. This is particularly significant in deep river lakes where thermal stratification of the water produces a stratification of the silt load, a warm muddy river, the hyperlimnorrheum flowing over a clear, cold lake, the hypolimnion, during the summer months.

Excepting the very quiet portions, erosion silt is quite uniformly distributed throughout the waters of rivers even in very deep holes, and in those river lakes in which there is no thermal stratification.

Erosion silt does not materially alter the salt complex or the amount of electrolytes in river waters.

Experimental studies demonstrated that layers of fine silt from one fourth of an inch to one inch thick produced a very high mortality among freshwater mussels living in gravel or sand beds, and in water which was otherwise unfavorable.

The amount of organic material carried to bottom with erosion silt ranged from 8 to 12 percent of the dry weight of the mud on the bottom of Lake Pepin and Lake Kelkuk.

The aquatic environment is affected by silt by: 1) reducing light penetration, 2) changing heat radiation, 3) covering the stream bottom, and 4) retaining organic and other material. Each of these effects is discussed.

Ellis, M. M. 1937. Detection and measurement of stream pollution. Bull. Bur. Fish. 48:365-437.

Effects of erosion silt on aquatic organisms by smothering of bottom fauna, covering of fish spawning grounds, mechanical action injury to gills and external structures and reduction of photosynthetic depth are briefly discussed.

Ellis, M. M. 1944. Water purity standards for freshwater fishes. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 2. 18 pp. (OR)

(1) Extensive field and laboratory studies of the freshwater streams of the United States show that general water conditions favorable to, not merely sublethal for, mixed faunae of game and food fishes of the "warm-water" types and supporting organisms, present a complex defined by:

(a) Dissolved oxygen not less than 5 ppm.

(b) pH range between 7.0 and 8.5.

(c) Ionizable salts as indicated by a conductivity between 150 and 500 mho x $10^{-6}$ at 25° Centigrade and in general not exceeding 1,000 mho x $10^{-6}$ at 25° Centigrade.

(d) Ammonia not exceeding 1.5 ppm.

(e) Suspensoids of a hardness of 1 or greater, so finely divided that they will pass through a 1,000-mesh (to the inch) screen; and so diluted that the resultant turbidity would not reduce the millionth intensity depth for light penetration to less than 5 meters.

(2) Experimental data are submitted supporting these field and laboratory findings.

(3) If such favorable conditions for fishes are to be maintained and fishes and other aquatic organisms are to be protected against the toxic actions of many stream pollutants, all pollutants not readily oxidizable or removable by the stream should be excluded, including particularly all cellulose pulps, wastes carrying heavy metallic ions and gas factory effluents. Other types of wastes should be diluted to concentrations nontoxic to the aquatic life of the particular stream. No substance should be added to stream waters which would cause a deviation in general conditions beyond the limits outlined above.

Ellis, M. M., B. A. Westfall, and M. D. Ellis. 1948. Determination of water quality. Res. Rep. No. 9, U.S. Fish Wildl. Serv. 122 pp. (OR)

This manual on water quality has been designed to present a system for the determination and evaluation of those conditions and substances of primary interest to the aquatic biologist, which occur in natural and polluted waters. Many of the procedures are applicable, however, to various problems in sanitary engineering and in trade waste disposal. The methods chosen have been used by the authors in the Water Quality Laboratories of the United States Fish and Wildlife Service and in actual field operations, in most cases, over a period of years. It has been possible in general, therefore, to select analytical sequences for which the technical limitations are rather well established. Where it seemed desirable, a choice of procedures, including both routine and research methods, is offered.

As water quality is a complex defined by the several specific characteristics of the water under examination, the designation of water quality depends upon the presence or absence of those substances which determine whether the water will serve a particular purpose. It is quite possible, therefore, to rate a given water as good for one use and poor for another. As the aquatic biologist is concerned for the most part with conditions which affect living aquatic organisms, the substances and characteristics discussed in this manual have been selected because they are essential to aquatic life, influence conditions which are essential, or are specifically harmful to aquatic organisms. However, water characteristics cannot be assembled under three simple groupings as this statement might imply, for the same substances may be harmful in one combination and innocuous in another. Nevertheless, certain conditions must be maintained in an aquatic environment if life is to survive even a short time, and certain others in addition are necessary if life is to continue successfully over a period of time. Therefore, the sequence suggested by the groupings given above has been followed in the general plan of the procedures presented here for the determination of water quality.

Emmett, W. W. 1976. Bedload transport in two large, gravelbed rivers, Idaho and Washington. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. Pp. 4-104 to 4-114. (OR)

Bedload transport in two gravelbed rivers has been measured by direct sampling in the Snake and Clearwater Rivers in the vicinity of Lewiston, Idaho. These rivers are large and capable of high flows producing mean depths in excess of 6 meters (20 feet) and velocities in excess of 3 meters per second (10/ft/s). At high values of streamflow when the rivers are competent to move almost all sizes of particles on the streambed, bedload-transport rates are correlative with a predictable proportion of stream-power expenditure. As streamflow decreases and the river loses competence to transport the coarser bed particles, the channel bottom becomes armored and limits the availability of smaller sizes material. As the channel becomes armored, the smaller material is transported at efficiencies that are greatly reduced from those predicted. Both rivers have a deficiency in bed material of intermediate sizes. Thus, median particle size of bedload shifts abruptly from very coarse gravel when all sizes of material are moving, to coarse sand when the channel bottom becomes armored.

Everest, F. H., and D. W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Board Can. 29:91-100. (OR)

During summer sympatric steelhead trout and summer chinook salmon segregated in Crooked Fork and Johnson creeks. In short-term allopatry, each species occupied the same types of habitat as in sympatry. Most age 0 steelhead lived over rubble substrate in water velocities and depths of less than 0.15m/sec and 0.15 m, respectively; most age 0 chinook lived over silt substrate in water velocities of less than 0.15m/sec and depths of 0.15-0.3 m; most age I steelhead resided over large rubble substrate in water velocities of 0.15-0.3m/sec (near bottom) and 0.75-0.9 m/sec (near surface), and in depths of 0.6-0.75 m. As fish of each species became larger they moved into faster, deeper water. Juvenile chinook and steelhead of the same size used the same physical space. But steelhead spawn in spring and chinook spawn in early fall, and disparate times of spawning create discrete intra- and inter-specific size groups of pre-smolts. The size differences minimize potential for social interaction, both intra- and inter-specific.

Everhart, W. H., and R. M. Duchrow. 1970. Effects of suspended sediment on aquatic environment. U.S. Bur. Reclamation, Project Completion Rep. 135 pp. (NTIS)

Effects of suspended sediment on aquatic fauna have been well documented in the literature. Sublethal concentrations of suspended sediment can be tolerated by organisms as long as mechanisms which remove sediment from the body surfaces function. Field studies on four high mountain streams in southwestern Colorado indicate no harmful effects on aquatic fauna from suspended solid concentrations. A quick and reliable method of measurement must be found to set standard limits on the amount of suspended sediment to be tolerated in streams near land-use operations. Turbidity measurement may be useful if: (1) a major portion of the total turbidity is contributed by suspended solids; (2) a relationship between turbidity readings and the weight per unit volume of suspended sediment exists; (3) a reliable meter can be found to given consistent readings. Turbidity is a questionable parameter to use as an index to suspended solids in water. Too many factors must remain constant before a turbidity reading can be converted to weight per unit volume of suspended solids. Suspended solids should be measured gravimetrically according to standard procedures suggested by the Federal Water Pollution Control Administration (1969).

Ferguson, D. E., J. L. Ludke, J. P. Wood, and J. W. Prather. 1966. The effects of mud on the bioactivity of pesticides on fishes. J. Mississippi Acad. Sci. 11:219-228.

Bioassy and gas chromatographic techniques demonstrated lethal units of enderin and DDT in muds from areas receiving runoff from insecticide treated cotton fields. Acetone extracts from such muds killed test fish. Mud containing sorbed pesticides failed to release lethal quantities of toxicants into standing $H_2O$.

Flaxman, E. M. 1959. Sediment concentration in streams of the Pacific Northwest. Pages 23-26 *in* E. F. Eldridge and J. N. Wilson, eds. Proc. of the Fifth Symposium--Pacific Northwest on Siltation--Its Sources and Effects on the Aquatic Environment. Portland, Ore.

The contributions of various streams in the Columbia Basin to the total sediment load of that area are presented in tabular form. Areas included are western and eastern Oregon and Washington, Idaho, British Columbia, and Montana.

Foley, M. G. 1976. Scour and fill in an ephemeral stream. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. Pp. 5-1 to 5-12. (OR)

The classical concept that mean bed elevation over an entire stream reach is lowered by scour during flood-wave passage and is restored by deposition in the waning flood phase (mean-bed scour and fill) can be challenged. The alternative that both scour and fill occur simultaneously at different migrating loci with a reach (local scour and fill) is more consistent with published field data. The field investigation reported herein suggests that mean-bed scour and fill in a natural uniform channel is minor compared to local scour and fill caused by bedform migration.

This experiment, utilizing a rectilinear array of buried maximum-scour indicators (scour-cords), produced data for contouring of maximum scour and fill in an ephemeral streambed during two floods. In the first flood, 24 cm (9.5 in) of scour and fill was measured for a bankfull flow depth of 23 cm (9 in). In the second, maximum scour and fill were at least 66 cm (26 in) for a bankfull flow depth of 34 cm (13 in).

Estimates of antidune amplitudes for the two floods, based on theoretical models and laboratory and field observations, are 28 to 64 cm (11 to 25 in) and 48 to 97 cm (19 to 38 in), respectively. This suggests that all scour and fill measured by the scour-cord array was caused by antidune migration.

Fredericksen, R. L. 1965. Sedimentation after logging road construction in a small western Oregon watershed. U.S. Dep. Agric. Misc. Publ. (illus.) 970:56-59. (OR)

During the summer of 1959, 1.65 miles of logging road were constructed in a 250-acre forested watershed that rises 2,000 feet in a distance of 1 mile. This study evaluates the change in sedimentation subsequent to road construction. Runoff from undisturbed watersheds in this area remains clear during the summer low-flow months and reaches concentrations of 100 parts per million during winter storm peaks. Runoff from the first rainstorms after road construction carried 250 times the concentration carried in an adjacent undisturbed watershed. Two months after construction, sediment had diminished to levels slightly above those measured before construction. Sediment concentrations for the subsequent two-year period were significantly different from preroad levels. In about 10 percent of the samples, sediment concentrations were far in excess of predicted values, indicating a streambank failure or mass soil movement. Annual bedload volume the first year after construction was significantly greater than the expected yield, but the actual increase was small. A trend toward normalcy was evident the second year.

Fredericksen, R. L. 1969. A battery powered proportional stream water sampler. Water Resource Res. 5(6):1410-1413. (OR)

A stream water sampler was designed and tested to sample water from a stream at a rate proportional to the streamflow rate. A composite of samples taken in this manner is an estimate of the mean concentration of constituents carried by the stream while the sample was collected. The instrument is suitable for estimates of transport of suspended or dissolved constituents in small streams. The sampler can be built for under $1000.

Gammon, J. R. 1970. The effect of inorganic sediment on stream biota. EPA Grant No. 18050DWC. U.S. Govt. Printing Office, Wash., D.C. 113 pp. (OR)

Fish and macroinvertebrate populations fluctuated over a four-year period in response to varying quantities of sediment produced by a crushed limestone quarry. Light inputs which increased the suspended solids loads less than 40 mg/l resulted in a 25 percent reduction in macroinvertebrate density below the quarry. Heavy inputs caused increases of more than 120 mg/l including some deposition of sediment and resulted in a 60 percent reduction in population density of macroinvertebrates. Population diversity indices were unaffected by changes in density because most taxa responded to the same degree. Experimental introductions of sediment caused immediate increases in the rate of invertebrate drift proportional to the concentration of additional suspended solids.

The standing crop of fish decreased drastically when heavy sediment input occurred in the spring, but fish remained in pools during the summer when the input was very heavy and vacated the pools only after deposits of sediment accumulated.

After winter floods removed sediment deposits, fish returned to the pools during spring months and achieved levels of 50 percent normal standing crop by early June. Slight additional gains were noted during the summer even with light sediment input. Only spotted bass (*Micropterus punctulatus*) was resistant to sediment, but its growth rate was lower below the quarry than above. Most fish were much reduced in standing crop below the quarry.

This report was submitted in fulfillment of project 18050 DWC under the sponsorship of the Water Quality Office of the Environmental Protection Agency.

Gangmark, H. A. 1962. The Mill Creek channel study. Presented at West. Div. Am. Fish. Soc., Seattle, Wash. (GS)

To learn how we might achieve the conditions desired in our spawning channel, we studied, among other places, the Sacramento River near Red Bluff. In test plants similar to the ones made in Mill Creek, (salmon) egg samples were eroded out of the streambed and lost in four out of five seasons. In the one successful year, in which we were able to measure our results, only 1.7 percent fry were produced.

In the fall of 1961, we moved the location of our river studies 40 miles upstream to a riffle near Redding where the tributaries entering the river, do so, below the Redding area.

Actual survival was 53.6 percent of the eggs planted or 74.4 percent of eggs that survived the initial handling and planting operation. As a result of comparing the differences between the Redding and Red Bluff stream sections we found the former had only 1/3 the fines. The streamflow at Redding was stabilized and heat storage in Shasta Reservoir was responsible for moderating and tempering water temperatures.

Gangmark, H. A. 1963. A view of the present status of spawning channels. Rep. Second Governor's Conf. on Pacific Salmon, convened by Governor Albert D. Rosellini Wash. Hyatt House, Seattle. (GS)

Advantages of improved production (salmon) areas usually include: stabilized streamflow, reduced silt loads, clean gravel, gravel sizes that preclude washout of eggs, and predetermined hydraulic gradients. They can also include temperature regulation of the streamflow below impoundments.

Disadvantages may include construction and maintenance costs and confinement that might limit the carrying capacity and, in one way, favor predators.

On a management scale the cost benefit of controlled flow may make such areas of controlled flow for salmon alone prohibitive. When tied in with other benefits, however, it can become feasible. For example, the water conservation and flood control programs that involve practically every stream in California can provide many acres of such control flow for the benefit of salmon.

Gangmark, H. A., and R. G. Bakkala. 1960. A comparative study of unstable and stable (artificial channel) spawning streams for incubating king salmon at Mill Creek. Calif. Fish Game 46:151-164. (GS)

With the knowledge that fast stream runoff was significant in the mortality of spawn, effort was directed toward finding exactly how severe runoff caused these losses. It was determined that mortalities were caused by both direct and indirect factors. Direct losses of spawn was due primarily to erosion of the streambed by high velocities of water. Information as to the fate of spawn washed out is not available, but it is reasonable to assume that once the eggs are washed from the protecting gravel bed out into the stream of violent water flow and shifting gravel, their chance of survival is low. Indirect losses of spawn occurred from a series of events of diverse and complex nature involving loss of spawning gravel and erosion of soil. Another series of events causing indirect loss of salmon spawn starts with soil erosion that clogs the redd. This blockage leads to: inadequate oxygen and poor delivery of oxygen to the eggs and poor cleansing of metabolic waste products.

Gangmark, H. A., and Robert D. Broad. 1955. Experimental hatching of king salmon in Mill Creek, a tributary of the Sacramento River. Calif. Fish Game 41:233-242. (GS)

The upper Sacramento River system continued to flood during the last stage of the experiment. The water gauge used by the California State Division of Water Resources was torn from its position by the flood. Records received from the Water Resources Branch of the United States Geological Survey show the Mill Creek rose to 5,240 cfs or approximately 100 times the flow recorded at the time the eggs were planted. The result was that all but six sacks of eggs (salmon) disappeared from the stream bed. Examination of the sacks that could be found revealed that none of the embryos had survived the floods. The shifting of the channel and the eroding and smothering action of silt and sand apparently caused a complete kill of the developing young salmon.

Gangmark, H. A., and Robert D. Broad. 1956. Further observations on stream survival of king salmon spawn. Calif. Fish Game 42(1):37-49. (GS)

The authors present evidence of a relationship between the occurrence of floods and the reduced survival of salmon eggs.

Garvin, W. F. 1974. The intrusion of logging debris into artificial gravel streambeds. Completion Rep. Ore. State Univ., Corvallis. 89 pp. (EPA)

The objective was to describe quantitatively the intrusion of logging debris into artificial gravel streambeds during conditions of low streamflow with a stable streambed, and begin an analysis of the effect of high flow and unstable streambeds. Prior studies indicated that logging debris was responsible for dissolved oxygen reduction within the gravel bed of spawning streams. Low flow stable streambed studies were conducted for eighteen to twenty days in a flume. Two high flow studies were also conducted. Samples were subdivided vertically into three sections and analyzed for pore volume, solid volume, and organic material present. Quantitative changes in organic material in each section of a sample were determined. These changes were compared with the depth of the sample, organic size class, position of the sample horizontally from a datum point, time, porosity, solid and pore volume, and rainfall during sampling days.

Gaufin, A. R. 1962. Environmental requirements of Plecoptera. Pages 105-110 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

While Plecoptera (stonefiles) constitute one of the smaller orders of insects, they are nevertheless one of the most important groups found in many streams. In mountain streams, they are a principal source of food for trout. Brinck reported that streams in Sweden with dissolved oxygen concentrations below 40 percent saturation had no stoneflies. Because of their preference for clear, well-aerated water, they are becoming increasingly important to limnologists as indicators of clear water conditions in pollutional surveys.

Practically all of the work that has been done to date on the North American stoneflies has dealt with their taxonomy and morphology. Despite the work that has been done, the nymphs of over 50 percent of our North American species have not yet been described. The position of zooplankton in polluted lakes and reservoirs is given.

A more complete knowledge of physiological differences of species is needed for understanding ecological effects of pollution on different species of planktonic Crustacea and for utilizing these species as biological indicators for water purity control purposes.

Gaufin, A. R. 1973. Use of aquatic invertebrates in the assessment of water quality. Pages 96-116 *in* Biological Methods for the Assessment of Water Quality, ASTM STP. Am. Soc. Testing Mat. (OR)

Pollution is essentially a biological phenomenon in that its primary effect is on living organisms. A biological investigation of a polluted lake or stream has several advantages over chemical analyses. It is less time-consuming because a single series of samples can reveal the status of the animal and plant communities which themselves represent the results of the summation of the prevailing conditions and are not affected by a temporary alleviation of a polluting effluent.

Intensive studies were carried out by Gaufin and Tarzwell in 1952 and 1956 to determine the effects of organic pollution on the aquatic communities of Lytle Creek and the value of these populations as indicators of pollutional conditions. The studies revealed that little reliance could be placed upon the mere occurrence of a single species in a given locality as an indicator of pollution. In the creek the nine species of macroinvertebrates which were most numerous in the septic zone also occurred in the recovery and clean water zones, but in much smaller numbers. The septic zone has less than one-fifth as many species as the clear water zone, but the total number of organisms per unit area was many times greater. The septic zone was characterized by species adapted to live in low dissolved oxygen concentrations or those able to secure their oxygen directly from the air.

In the clean water zone there was a great variety of invertebrate communities, each consisting of many different species. Most of the species which occurred in the septic and recovery zones were also found in very limited numbers in the clean water zones. In addition, there was also present a wide variety of forms which were intolerant of conditions in the polluted zones. Most of these were the gill-breathing, immature stages of such insects as the mayflies, stoneflies, caddis flies, and alder flies.

In evaluating the reliability of aquatic organisms as indicators of pollutional conditions and water quality, one must consider the different indicator organisms not separately but as biological associations or communities.

Gessler, J. 1975. Research needs as related to the development of sediment standards in rivers. Office Water Res. Tech., Completion Rep. 39 pp.

This report includes a position paper by the author as well as a summary of the proceedings of a workshop assembled to discuss the problems associated with the development and establishment of sediment standards for rivers.

Some specific points mentioned were:

1. Problem areas in setting standards include the establishment of natural adjustment ranges and variations in a river, the contribution of sediments from human interference, and the effect on the river environment brought on by changes in the sediment load.

2. The setting and controlling of standards is difficult because natural sediment levels are likely to be very variable, and the river environment may well be adjusted to the pollutant.

3. Bedload research when related to the corresponding suspended sediment load is needed.

4. Turbidity levels are unacceptable to standards. "The ideal standard would certainly be one which relates to the total sediment transport characteristics of the stream, i.e., to the sediment transport of each grain size, as a function of water discharge or stage."

5. Biotic and geomorphic characters of a region's streams and rivers might well be used conjointly in determining the standards.

Gessler, J. 1976. The dilemmas of setting sediment standards. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. Pp. 2-158 to 2-268. (OR)

Society has a multitude of interests in the quality of our rivers as it related to the movement of sediment. Some of these interests are directly contradictory to each other. Reducing suspended sediment loads in the interest of water quality as related to domestic and industrial use or as related to recreational purposes may result in offsetting the delicate equilibrium of the river's biota due to changes of the food supply or may lead to drastic changes in the river's geomorphic structure. With the biotic and geomorphic characteristics changing from river to river sediment standards cannot have the form of absolute upper and lower limits for the total sediment transport. They must be tied to the past history of the individual river.

Standards without enforcement are meaningless. This will require monitoring the total sediment transport at strategic locations. Selection of such locations again leads to a dilemma. Deviations in sediment transport from some baseline data must be investigated and their cause determined, whether it is natural or man-induced. In order to do so the deviations must be relatively strong and the number of possible sources relatively small. This demand puts the monitoring stations into the far upstream regions of the watersheds. But this will require a large number of stations which makes the monitoring at these locations economically unfeasible.

Ideas for possible solutions are suggested. Special emphasis is on areas in which knowledge is insufficient for reaching any conclusions and will require extensive research efforts.

Gibbons, D. R., and E. O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. USDA For. Serv., Gen. Tech. Rep., PNW-10. 145 pp. (OR)

This bibliography is an annotation of the scientific and nonscientific literature published on the effects of logging on fish and aquatic habitat of the western United States and Canada. It includes 278 annotations and 317 total references. Subject areas include erosion and sedimentation, water quality, related influences upon salmonids, multiple logging effects, alternation of streamflow, stream protection, multiple use management, streamside vegetation, stream improvement, and descriptions of studies on effects of logging. A review of the literature, a narrative on the state of the art, and a list of research needs determined by questionnaires are included.

Graves, D. S., and J. W. Burns. 1970. Comparison of the yields of downstream migrant salmonids before and after logging road construction on the South Fork Caspar Creek, Mendocino County. Calif. Fish Game, Inland Fish. Admin., Rep. 70-3. 11 pp. (GS)

Yields of juvenile steelhead rainbow trout (*Salmo gairdnerii gairdnerii*) and silver salmon (*Oncorhynchus kisutch*) emigrants were compared in South Fork Caspar Creek, a small coastal stream in Mendocino County, California, before and after construction of a logging road along the stream in the summer of 1967. Numbers, lengths, and age class structures were compared.

There were 138 percent more steelhead smolts and 41 percent fewer silver salmon smolts in 1968 (first spring following road construction) than there had been in 1964 (preroad construction). Increased emigration of steelhead smolts in 1968 was probably caused by a decrease in favorable living space. The decrease in salmon smolts accompanied high mortalities during road construction. Eighty-three percent of the total salmon population and 86 percent of the total steelhead population died or emigrated from the affected area during the road construction from June to October 1967. The combined populations of steelhead and salmon smolts decreased 20 percent. This combined decrease is within the range of natural fluctuation reported from other California streams; however, there is no doubt that road construction contributed to the decrease in Caspar Creek.

Steelhead and salmon fry were more numerous in 1968 than in 1964. No steelhead fry were trapped in 1964, while 72 percent of the migrants trapped in 1968 were fry. The age composition of the salmon also shifted markedly from 1964; fry comprised 5 percent of the total in 1964 and 81 percent in 1968. This increase in numbers of emigrating fry in 1968 could have resulted from poor environmental conditions.

Steelhead smolts were smaller in 1968 than in 1964, while salmon smolts were larger. Salmon fry were smaller in 1968. Steelhead fry cannot be compared as none were trapped in 1964. The increase in length of the salmon smolts may have resulted from a decrease in competition due to higher mortality in 1967. The fry may have been smaller due to unfavorable intragravel conditions during incubation. Comparison of steelhead smolts is difficult because of the emigration of more than one year class. The decrease in average length, however, supports the hypothesis of premature emigration due to unfavorable habitat.

Griffin, L. E. 1938. Experiments on the tolerance of young trout and salmon for suspended sediment in water. Bull. Ore. Dep. Geol. 10, Appen. B. Pp. 28-31. (GS)

The preliminary examination of data from a study on the tolerance of young trout and salmon to suspended sediment indicated that young trout and salmon are not directly injured by heavily silted water. Experimental design and controls were found lacking. Results are inconclusive.

Grissinger, E. H., and L. L. McDowell. 1970. Sediment in relation to water quality. Water Resources Bull. 6(1):7-14. (OR)

The relation between sediment and water quality involves the individual relations between sediment and the physical, chemical, and biological characteristics of water as these characteristics determine the suitability of water for an intended use. Both the physical and chemical properties of fine-grained sediments must be considered in evaluating these relations, whereas only the physical properties of coarse-grained sediments are significant. Most of the literature concerning this subject has considered sediment only as a physical entity. In amount, it is the prime pollutant and is one of the major considerations in evaluating the suitability of water for an intended use. Losses in the United States from sediment and associated flood water damages are measured in billions of dollars annually. Sediments also indirectly affect water suitability through their (physical) influences on biological activity. Fine-grained sediments, that is, clay minerals and amorphous and organic materials, have chemically active surfaces. These sediments may either absorb ions from solution or release ions to solution depending upon the chemical environment. Unfortunately, not enough is known about the ternary system--sediment-water-dissolved chemical load--to adequately define its influence on either the biological characteristics of water or the suitability of water for various long-term uses. This paper attempts to define the problems concerning the role of sediment in this ternary system.

Guy, H. P., and V. W. Norman. 1970. Field methods for measurement of fluvial sediment. Techniques of water resources investigations of the U.S. Geological Survey. U.S. Govt. Printing Office, Wash., D.C. Book 3, Chapt. c-2. (OR)

This report describes field methods for the measurement of fluvial sediment. The diversity of the hydrologic and physical environments and data requirements therefrom make it desirable that the persons involved in sediment measurements be familiar with the basic sediment concepts and the equipment and techniques to be used for making timely and efficient sediment measurements.

In an addition to an introduction, the report consists of two main sections. The section on "Sediment sampling equipment" includes a discussion of the characteristics and limitations of commonly used samplers and some of the modifications of this equipment for special measurements. The other section on "Sediment sampling techniques" includes a discussion of the characteristics of measurement sites, the selection of sampling verticals and transit rates, the methods of making sediment-discharge measurements, sampling quality control and timing, and some of the requirements for sediment-related data.

Hall, J. D. 1967. Alsea Watershed study. Ore. State Univ., Dep. Fish Wildl. Pam., Corvallis. 11 pp. (EPA)

This pamphlet is a guide to the Alsea study area and an outline of the research underway to determine the effects of logging on aquatic resources. Areas of research include: hydrologic studies; soil vegetation survey; streamflow, sediment, and water temperature; chemical and bacteriological water quality; and fishery studies. The pamphlet presents some initial results from the study.

Hall, J. D., and R. L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. Pages 355-375 *in* G. Northcote, ed. Symposium on Salmon and Trout in Streams. Inst. Fish., Univ. Brit. Columbia. (OR)

The effects of two patterns of Douglas fir logging on water quality and fish populations have been studied in three coastal headwater streams. Clearcut logging of an entire watershed of 71 hectares (175 acres) is being compared to clearcutting patches on a larger watershed of 304 hectares (750 acres), where about 30 percent of the area has been harvested and a strip of timber left along the stream. The third watershed of 203 hectares (500 acres) will remain unlogged as a control. Pre-logging studies began in 1958, access roads were constructed in 1965, and logging took place in 1966.

Substantial changes in temperature and dissolved oxygen content of stream water followed logging in the entirely clearcut watershed. A maximum temperature of 30°C and a maximum diurnal fluctuation of 16° were recorded. Comparable pre-logging maximums were 16° and 1.5°, respectively. Dissolved oxygen levels of surface and intragravel water dropped below 2 mg/l during logging operations. Survival of coho salmon and cutthroat trout in the clearcut watershed has been affected by logging, but the significance of the effect cannot yet be fully evaluated.

No significant changes in the fish population or its habitat have been noted in the patch-cut watershed. Studies will continue for several years to evaluate long-term effects of logging on the stream and to determine the period of recovery.

Hamilton, J. D. 1961. The effect of sand-pit washings on a stream fauna. Verh. Int. Verein. Limno. 14:435-439.

Effects of washings from sand and gravel pits on aquatic biota were investigated. High turbidity produced by finely divided particles did not adversely affect the bottom fauna in a shallow biotic environment. Suspended sand and silt had no direct effect on fishes. Indirect effects were considerably deleterious to spawning and development--curtailed spawning entirely--however, six months after sediment discharge was stopped, "fish were reported to have used some of the spawning sites in the region previously affected by the discharge."

Hansen, E. E. 1970. Sediment movement in a pool and riffle stream. Int. Assoc. Sci. Hydrol., Publ. No. 96. Pp. 541-561. (OR)

A sediment budget was constructed for a pool and riffle stream along which eroding streambanks were the dominant sediment source. Total sediment load was measured with a DH-48 sediment sampler at artificial sills placed on the streambed at each of the five sampling stations, which eliminated an "unsampled zone." Supplementary data collected at each station and an independent check with a long-term reservoir fill rate indicated the "sill samples" were accurate measures of total load for a wide range of sampling site hydraulic characteristics. The total load data were used to determine the impact of eroding bank sediments on both sediment load and streambed composition. Total load increased 530 percent along a 26-mile (42 kilometers) section of main channel; most of this increase came from eroding streambanks. However, particle-size distribution of the predominantly sand-size sediment load remained the same along the section of stream. The proportion of streambed area in sand decreased downstream, while the proportion in cobble and boulder increased--an apparent result of increased stream gradient. Although sediment load was related to stream discharge, it was believed to be dependent upon sediment delivery rate to the stream.

Hansen, E. A. 1971. Sediment in a Michigan trout stream, its source, movement, and some effects on fish habitat. USDA For. Serv., Res. Pap. NC-59., N. Cent. For. Exp. Stn., St. Paul, Minnesota. 14 pp. (GS)

A sediment budget was constructed from three years of measurements on a pool and riffle stream. Total sediment load increased five times along a 26-mile length of stream; most sediment came from 204 eroding banks. Three-fourths of the total sediment load was sand size. The area of streambed covered with sand decreased downstream, indicating that the transporting capacity of the stream exceeded sediment supply. Complete streambank stabilization would reduce the sediment load by about half and probably result in streambed composition changes beneficial to trout.

Hansen, E. A. 1973. In-channel sedimentation basins a possible tool in trout habitat management. Prog. Fish Culturist 35(3):138-142. (BA)

Design and use of sedimentation basins for trout habitat management are discussed. Minimum basin size for trapping bedload sediments is based on Vetter's formula. Basins can remove essentially all moving bedload from a section of stream; whereas traditional "stream improvement" measures may decrease bedload sediments up to only 50 percent. Sediment reduction programs using basins will produce the maximum possible change in streambed composition. Basins are effective for trapping sand size and larger sediment and have the advantage that they could be located immediately upstream from critical zones such as spawning areas.

Hansen, E. A., and G. R. Alexander. 1976. Effect of an artificially increased sand bedload on stream morphology and its implications on fish habitat. Pages 3-65 to 3-76 *in* Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. (OR)

Sand sediment has been added daily for nearly four years to a low gradient Michigan trout stream to determine effects on stream morphology, water temperature, and ultimately the trout population. Daily sand input is adjusted so that the average sediment concentration is increased by a factor of four over the pretreatment concentration of 20 mg/l. Sediment discharge is measured just upstream of the sand input point, and also at the lower end of the treated section, 1.6 km (1 mile) downstream. Permanent stream cross-section stations are spaced at 30-m (100-foot) intervals along the 1.6-km (1-mile) control and treated sections to facilitate the measurement of channel changes. The trout population is inventoried twice a year to determine its response to the increased sand bedload.

The added sand with its resultant streambed aggradation has produced increases in stream gradient and width, and decreases in stream depth and in the total static volume of water. The stream gradient and channel form are more uniform throughout the treated reach due to pool filling. Streambed composition has changed substantially; gravel areas have decreased, sand areas increased. Water temperatures are slightly warmer in summer and cooler in winter due presumably to the wider shallower stream. The impact of these changes on the trout population will be reported at a later date to allow time for population responses, if any, to occur.

Hansmann, Eugene W., and H. K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. Ecology 54(1):194-199. (OR)

Changes in the stream algal flora were observed during a multidisciplinary logging study of small watersheds in Oregon. Clearcut logging was applied to one watershed of 71 hectares, while a second watershed of 304 ha was patch-cut leaving a buffer strip of vegetation along the stream channel. A third watershed of 203 ha was not logged but remained as a control. Pre-logging and post-logging oxygen levels, temperature, and sedimentation loads were analyzed. Access roads were built in 1963, and logging completed in 1966.

Analysis of the algal communities of the three watershed streams prior to the logging operation of 1966 indicated that the communities were predominantly a periphyton type composed mainly of diatoms. Immediately following the yarding operation of the clearcut watershed, large quantities of *Sphaerotilus natans* colonized all debris and mud in the stream, and a change in the algal flora appeared to take place. Large mats of green algae were observed colonizing all mud and slash. Results from glass substrates indicate that some changes may have taken place in the diatom community.

Harrison, A. D. 1962. Some environmental effects of coal and gold mining on the aquatic biota. Pages 270-274 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

Gold and coal mining in South Africa, as in other parts of Africa, have marked effects on streams draining the mining areas. These effects are of two main types: 1. *Silting.* This is particularly marked in gold-mining regions where huge volumes of crushed rock are deposited in dumps as fine sand, and powdered ore is deposited in slimes dams after cyanide extration. 2. *Pollution by acid sulphates.* During both types of mining, when pyrite is exposed to air and water, it is oxidized by bacteria into ferrous and ferric sulphate, with or without free sulphuric acid.

Harrison, C. W. 1923. Planting eyed salmon and trout eggs. Trans. Am. Fish. Soc. 53:191-200.

The effects of different gravel compositions in experimental redds are recounted. Early observations on the effects of silt and sand on the survival and emergence of salmonid fry are described.

Hayes, F. R., I. R. Wilmot, and D. A. Livingstone. 1951. The oxygen consumption of the salmon egg in relation to development and activity. J. Exper. Zool. 116:377-395. (OR)

The present paper presents the results of a study of the oxygen consumption of developing eggs of *Salmo salar* up to the time of hatching. The work was carried out at Dalhousie University during the winters of 1947-50, making use of eggs supplied by several hatcheries in Nova Scotia. The eggs were reared either in running city tap water or in constant temperature tanks in which the water was mixed by aeration and stirring. The mortality of eggs reared in the constant temperature tanks was high, and for that reason the records of attempts to examine the effect of temperature on respiration have been for the most part omitted from the present paper. Unless otherwise stated, the developmental and experimental temperature was 10°C. This work was aided by grants from the National Research Council of Canada and the National Cancer Institute of Canada.

Helley, E. J. 1969. Field measurement of the initiation of large bed particle motion in Blue Creek near Klamath, California. Sediment transport in alluvial channels. USGS Prof. Pap., No. 562-G. 19 pp. (OR)

More than two-thirds of the field measurements of bed velocity necessary to initiate motion of coarse natural particles whose size, shape, specific gravity, and orientation angle were known agree within 20 percent of those velocities predicted from theory. The theory is based on balancing turning moments of the fluid forces of drag and lift with the resisting moment of the submerged particle weight.

Initial motion seems to depend more on size and shape than on specific gravity or orientation angle. In fact, shape differences almost completely compensate for the differences in specific gravity ranging from 2.65-3.00 and orientation angles ranging from 0°-25°.

Bed velocities necessary to initiate motion of coarse bed material in Blue Creek are equaled or exceeded about 5 percent of the time. This fact and changes in channel topography and cross-section area emphasize the ability of perennial mountain streams to transport coarse bed material frequently.

Helmers, A. E. 1966. Some effects of log jams and flooding in a salmon spawning stream. USDA For. Serv. Res. Note NOR-14. 4 pp. (EPA)

Streambed scouring and deposition occured in the areas of two constructed log debris jams. Gravel shifting occured and may have been responsible for the increased dissolved oxygen concentration.

Log debris jams intensify streambed instability, especially during floods. They may reduce salmon production in otherwise favorable areas. Gravel movement presumably reduces egg and larvae survival. On the other hand, loss of fine material because of gravel movement should benefit the salmon development environment by improving intragravel waterflow, thus increasing dissolved oxygen availability and making possible more effective removal of metabolic wastes. The effect of log-debris jams on salmon production remained undetermined. However, temporary or unstable jams were judged to be detrimental.

Herbert, D. W. M., J. S. Alabaster, M. C. Dart, and R. Lloyd. 1961. The effect of china-clay wastes on trout streams. Int. J. Air Water Poll. 5(1):56-74. (M)

In some Cornish rivers suspended matter from china-clay workings is the only important polluting material, and such streams provide good sites for investigating the effect of chemically inert suspended solids on fisheries, since there are other nonpolluted streams of similar size nearby. This paper describes a survey made during May 1960 to determine the status of the brown trout (*Salmo trutta* L.) in both clean and polluted parts of the Rivers Par, Fal, and Camel, and also in two unpolluted streams, the Subulyan, which is a tributary of the Par, and the Tresillian. The concentrations of suspended matter, the numbers, size and age of the trout, and the amount of food available to them in these streams were investigated.

Herbert, D. W. M., and J. C. Merkens. 1961. The effect of suspended mineral solids on the survival of trout. Int. J. Air Water Poll. 5:46-55. (M)

A study on the effects of mineral solids, kaolin and diatomaceous earth, suspensions on young rainbow trout. Results show that 270 ppm kaolin and diatomaceous earth produced significant mortalities (50 percent or more). Suspended sediments in concentrations up to 270 ppm had no apparent effect on growth of the test fish after 4-1/2 months. However, concentrations of 270 and 810 ppm kaolin and diatomaceous earth did produce pathological changes in gill tissue and some instances of fin rot.

Herbert, D. W., and J. M. Richards. 1963. The growth and survival of fish in some suspensions of solids of industrial origin. Int. J. Air Water Poll. 7:297-302. (M)

Suspensions of coal-washery solids and spruce fibers were used in tests of the effects of suspended solids on rainbow trout. It was found that concentrations of up to 200 ppm coal-washery solids produced no moralities. Concentrations of 200 ppm wood fiber produced a slow, steady mortality in test fish populations. The dead fish showed signs of fin rot. Wood fiber in concentrations of 100 ppm also produced fin rot in test fish. The results of a questionnaire inquiring into the effects of discharges of china-clay solids on fisheries in streams of the United Kingdom are also presented.

Herrington, R. B., and K. K. Dunham. 1967. A technique for sampling general fish habitat characteristics of streams. Intermountain For. Range Exper. Stn., USDA For. Ser. Res. Pap., INT-41. (OR)

It is not practical to completely measure the varying elements of all streams. This paper describes a sampling technique for taking measurements along selected transects across streams. When tested on three streams, the results provided acceptably precise estimates of stream length and width, surface area, pool area, riffle area, depth, and streambed composition, as well as of the stability and vegetative cover of the streambanks.

The data obtained from the technique reported here can help the land manager make effective interim plans and avoid costly mistakes particularly in recreation developments.

In addition, the data are sufficiently definitive and descriptive so that they could be used as a benchmark to determine the magnitude of future changes that may occur.

Hobbs, D. F. 1937. Natural reproduction of quinnat salmon, brown and rainbow trout in certain New Zealand waters. New Zealand Mar. Dep. Fish., Bull. 6. 104 pp. (OR)

(1) The efficiency of fertilization of the eggs of quinnat salmon and of brown and rainbow trout, lodged in natural redds in streams, is remarkably high. Material from redds of brown trout showed an efficiency of fertilization in excess of 99 percent.

(2) The incidence of subsequent loss, where heavy loss occurs, is much greater in the pre-eyed than in the eyed ova or in the alevin stage.

(3) Heavy losses of fertilized ova are the outcome of adverse environmental conditions and not of inherent weakness.

(4) The extent of losses of fertilized ova in undisturbed redds depends primarily on the amount of very fine material in the redds during the development of ova before eyeing. It is possible that high water temperature is a contributing cause of loss.

(5) *Saprolegnia* infection of dead pre-eyed eggs is responsible for losses of ova at later stages.

(6) Losses, of unmeasured extent, of the ova of brown trout occur through the superimposition of redds where suitable spawning areas are of insufficient size for the number of fish which occupy them.

(7) All floods tend to be harmful in that they increase the deposition of fine material in redds.

(8) Floods rarely effect the substantial modification of the contours of redds. When they do so they may cause losses considerable enough to account for the partial failure of a year class.

(9) Under favorable conditions natural reproduction is a highly efficient process.

(10) The fact that favorable conditions were found to exist not uncommonly in streams in a belt of country embracing a great variety of conditions suggests that the efficiency of natural spaning in Salmonidae in New Zealand may be generally higher than was heretofore supposed.

Holland, G. A., J. E. Lasater, E. D. Neumann, and W. E. Eldridge. 1964. Toxic effects of organic and inorganic pollutants on young salmon and trout. State of Wash. Dep. Fish., Res. Bull. No. 5, second printing. 264 pp. (M)

Industrial and municipal pollution are a threat to Washington's fishery resources. This study investigated the toxic properties of some industrial wastes and byproducts, both organic and inorganic, which are known to be discharged into estuaries and rivers of the Pacific Northwest. Because of their importance to the fishing industry of the state, young salmon and trout were used as study animals.

Hollis, E. H., J. G. Boone, C. R. LeLose, and G. J. Murphy. 1964. A literature review of the effects of turbidity and siltation on aquatic life. Staff Rep., Dep. Chesapeake Bay Affairs, Annapolis, Md. (mimeo). 26 pp. (GS)

The detrimental effects of turbidity and siltation upon aquatic life are reviewed. The report contains a fairly extensive bibliography.

Hornbeck, J. W., and K. G. Reinhart. 1964. Water quality and soil erosion as affected by logging in steep terrain. J. Soil Water Conser. 19(1):23-27. (OR)

The experiment demonstrated that excessive damage to water quality can be avoided even when logging on steep terrain. Measured maximum turbidities of streams were 56,000 p.p.m. on the commercial clearcut area and only 25 ppm on the intensive selection cut watershed. Most of the damage to water quality occurred during and immediately after logging.

Recommended forestry practices discussed include: planning of the logging operation: proper location, drainage, and grade of skidroads; and timely completion of the operation in any specific area. In most respects, practices recommended for watershed protection also contribute to the overall efficiency of the logging operation.

Huet, M. 1962. Water quality criteria for fish life. Pages 160-167 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

For a particular habitat to be suitable for fish, it is necessary that the fish should be able to live and develop there. This means that the environmental factors for respiration, feeding, and reproduction should be suitable. Environmental requirements vary considerable from one kind of fish to another. Within various types of water, the following distinctions should be made: salmonid waters, mixed waters, and cyprinid waters.

Reasonably precise criteria can only be given for certain factors: temperature, dissolved oxygen, and pH. Care must be taken to avoid confusing the extremes for these factors and the optimum value for the same factor. These details are discussed in the text. Other environmental factors are also discussed.

Hunt, R. L. 1969. Effects of habitat alteration on production, standing crops and yield of brook trout in Lawrence Creek, Wisconsin. Pages 281-312 *in* T. G. Northcote, ed. Symposium on Salmon and Trout in Streams. Univ. Brit. Columbia, Vancouver. (OR)

Section A, the upper mile of Lawrence Creek, was intensively altered by the addition of bank covers and current deflectors during 1964. These alterations reduced the surface area by 50 percent, increased average depth by 60 percent, increased pools by 52 percent, and increased permanent overhanging bank cover for trout by 416 percent. Sand substrate was reduced by 40 percent, silty bottom was reduced by 70 percent, but gravel bottom area was increased by 11 percent.

The management objective was improvement in the sport fishery by increasing the number of naturally produced legal-sized trout. Production, standing crops and yield before (1961-63) and after (1965-67) alteration were also compared.

1. The average number of legal-sized trout (8-inch plus) present when the fishing season began increased by 156 percent (from 188 to 303 per section).

2. Annual production increased by 17 percent (from 261 to 306 pounds per section).

3. Mean standing crop of trout increased by 40 percent (from 43 to 124 pounds per section). Age I+ trout accounted for 78 percent of average standing crop before alteration, but 87 percent after alteration.

4. Yield increased by 196 percent (from 23 to 68 pounds per section).

5. Food consumption increased by 28 percent (from 1,827 to 2,337 pounds per section.

Improvements in the trout population appeared to be largely the result of increased rates of overwinter survival rather than greater recruitment of young trout or increased growth rate. Changes in production and standing crops were greater for age I+ trout than for age 0 trout.

Relationships of production to standing crops and consumption are discussed and also comparisons of production, standing crops, consumption and yield in section A versus section B, the unaltered adjacent reference zone.

International Pacific Salmon Fisheries Commission. 1966. Effects of log driving on the salmon and trout populations in the Stellako River. Int. Pac. Sal. Fish. Comm., Prog. Rep. 14. 88 pp. (OR)

Field and laboratory investigation of effects of log driving on the fish populations of Stellako River were carried out during 1965. Field studies showed that log jams caused damage to approximately eight percent of sockeye spawning grounds by erosion of gravel and bark deposition. That the damage was real was verified through analysis of subsequent spawning distribution which showed that spawners tended to avoid the damaged areas. Laboratory results indicated that moderate gravel disturbance due to erosion and gouging by individual logs could also have killed incubating trout eggs in Stellako River, but that vertical impact on the gravel surface would have caused only occasional mortality.

Isaac, P. C. G. 1962. The contribution of bottom muds to the depletion of oxygen in rivers, and suggested standards for suspended solids. Pages 346-354 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent. (OR)

Questions are posed as to whether bottom muds in sedimented or resuspended states contribute to the oxygen demand of rivers, and whether it is feasible to impose suspended-solids standards on effluents to limit bottom deposits. The influence on oxygen demand of dissimilation products from the sediment is discussed.

It has been well-established that bottom and resuspended muds do exert an oxygen demand. The relative contributions of settled deposits and resuspended solids to oxygen demand vary widely according to the degree of resuspension. Resuspended bottom muds cause a marked reduction in the dissolved oxygen concentration.

Several investigators have concluded that the oxygen demand of sludge deposits is independent of the dissolved oxygen concentration in the supernatant water. It is the rate of upward diffusion to the surface of the sediment of the oxidizable substances produced anaerobically within the deposits that controls the rate of benthal oxygen demand.

The extent to which bottom muds are resuspended in flowing water varies greatly according to circumstances prevailing in different rivers. The amount of resuspension determines the degree of oxygen depletion, which is much greater from suspended solids than from stationary bottom deposits. Laboratory tests showed that a one-ppm concentration of detergent (ABS) decreased the settling rate of any given concentration of mud.

Control of the amount of suspended solids discharged to a stream or lake is definitely required. Such control will normally result in a relatively non-turbid stream. The quality of the diluting water must be specified since water taking up much dissolved oxygen is, in itself, of doubtful purity.

Jannasch, H. W., and P. H. Pritchard. 1972. The role of inert particulate matter in the activity of microorganisms. Mem. Ist. Ital. Idrobiol. 29 Suppl.:289-308. (OR)

Suspended organic and inorganic particulate matter, not available to microbial attack *per se*, was shown to affect growth and metabolism of bacteria. The rate of oxygen uptake and the degree of attachment of bacterial cells to particles were influenced by the concentration of dissolved nutrients (carbon and energy source), the particle density, and the nature of the particulate material. Chemostat experiments demonstrated an effect of particle suspensions on competition of bacterial species for a particular organic substrate and on the ratio of intermediate products formed during its degradation.

Johnson, B. W., E. M. Miller, and C. H. Ellis. 1952. A report on steelhead egg and fry survival experiments on the North Fork of Stillaguamish River with relation to the North Fork earth slide. Unpubl. Rep., Wash. State Fish. Dep. (GS)

The silting of the slide in the Stillaguamish River has a very definite effect on development of eggs and fry for a limited distance of less than one mile below the slide and in that area causes 50 percent to 100 percent loss of eggs and fry.

From one mile to five miles below the slide no significant difference could be observed in loss of eggs and fry from silting effects (a 33.5 percent survival).

Comparing survivals from a distance of one mile or more below the slide and survivals above the slide a very maximum of 10 percent loss to eggs and fry could be assessed to silting of the river. (Authors buried steelhead eggs in plastic sacks in gravel).

Jones, B. G., N. M. Howard, C. C. Meek, and J. Tomkins. 1974. Transport processes of particles in dilute suspensions in turbulent water flow. Phase III Res. Rep. Office Water Res. Tech., Wash., D.C. 110 pp. (OR)

Understanding the basic mechanisms and predicting the behavior of particles suspended in turbulent fluid flow are essential to environmental conservation and to multiphase system design. Air and water pollution, sedimentation and erosion of river beds and coastal shorelines, and atmospheric fallout are some of the areas in which particle suspensions are of key importance. Detailed experimental measurements of dilute particle suspensions have been performed which examined the effects of particle size, shape and relative density on the statistical response of such particles in a turbulent fluid. Shape was found to be of minor importance for spheres, cubes and tetrahedrons. However, size was found to be important when the particle dimension was as large or larger than the fluid turbulence structure. Relative density influenced both free fall and inertial effects. An analytical model was developed which included these latter effects. It agrees well with observed particle dispersion measurements.

Kalinske, A. A. 1947. Movement of sediment as bed-load in rivers. Trans. Am. Geophys. Union 28(4):615-620. (OR)

The movement of sediment which rolls and creeps along the bed of a river, and is known as bed load, is analyzed using basic physical principles of fluid dynamics. The conditions for the start of sand-grain movement are set down and form an important part of the analysis. The turbulence mechanism in the flow above the bed plays a most significant role in the analysis of rate of bed-load movement. The final equation developed for the rate of sediment transport is not empirical; all the numerical constants in it are definite physical measures either of the sediment or of the hydraulic and turbulence characteristics of the river. The equation fits laboratory and field data obtained for a wide variety of conditions by various experimenters.

Katz, M., and C. E. Woelke. 1967. Water quality requirements of estuarine organisms. Pages 90-99 *in* Water Quality Criteria, ASTM STP 416. Am. Soc. Testing Mats. (OR)

The disposal of industrial and domestic wastes into the estuarine and marine environment is feasible and practical. Properly designed disposal systems can distribute wastes so that the other beneficial uses of the aquatic environment are not harmed. A prerequisite to the planning of the disposal system is a knowledge of the life history and ecological requirement of the important aquatic species which utilize these environments. The estuarine environment is an extremely variable one, and the organisms that utilize this habitat have specialized life histories that have enabled them to adapt to these conditions. Some fish, the salmonids, migrate through the estuary at certain limited times of the year, and water quality must not impede free migration. Shrimp reproduce in the open ocean and feed in the estuaries. Some fish species use the estuaries only for a spawning and nursery area for their young, and only utilize the estuary at certain times of the year. Oysters remain in the estuary throughout the year; the shelled adults can close their shells and survive a toxicity episode, but their free-swimming larvae are very sensitive, and a population can be destroyed readily by toxic effluents. A good deal of material on the ecological requirements of the important marine species is available and should be applied by those responsible for waste discharges in the estuarine and marine environment in order to protect the important biological communities.

Kelley, D. W. 1959. Effects of siltation on production of fish food organisms. Pages 13-15 *in* E. F. Eldridge and J. N. Wilson, eds. Proc. Fifth Symposium--Pacific Northwest on Siltation--Its Source and Effects on Aquatic Environment.

The author discusses the relative importance of fish food organisms and availability of shelter as affected by siltation. He also emphasizes the need for establishment of permissible levels of silt and sand in streams and lakes and determination of effects in oceans and deltas.

Kelly, D. W. 1962. Sedimentation helps destroy trout streams. Outdoor Calif. 23(3):4, 5, 10, 11. (GS)

The effects of sediment on the basic needs of a trout population--its food, shelter, and a place to reproduce--are discussed.

Kingsbury, A. P. 1973. Relationship between logging activities and salmon production. Completion Rep. July 1970-June 1972. 59 pp. (EPA)

Sediment content of spawning areas in 108 Creek increased over a six-year period as logging progressed in the watershed but did not change appreciably in the following three years as cutting shifted away from the main stream. Marked changes in sediment content of Kadashan Creek spawning areas also occurred although logging has not yet begun. The geological, hydrological and biological characteristics of the two streams differ widely. The effects of sediment content changes upon the production of pink salmon fry in the two streams cannot be effectively separated from the effects or other environmental variables. An analysis of the relationship between fine sediment and intragravel oxygen in the two streams was inconclusive.

Klages, M. G. 1972. Sources in sediment in a mountain river basin. Completion Rep., July 1, 1970 to June 30, 1972. Water Resources Res. Cent. 16 pp. (OR)

Turbidity measurements can be used to estimate suspended solids in water from a single watershed. The accuracy of the estimate can be improved by removing the sand and measuring it gravimetrically. Sediment yield is strongly influenced by geology of the drainage area. Mineralogy of the suspended material is also influenced by geology but to a lesser extent. Mineralogical measurements can be used to trace the sources of sediments where differences in geology exist within a watershed. They work best on smaller watersheds where the number of tributaries is small and distances short. They are probably best used in conjunction with other measurements such as suspended load and streamflow. X-ray diffraction patterns can be used to determine whether the major source of suspended clay in a stream is sheet erosion of weathered surface soil or erosion of unweathered subsoil and geologic materials.

Knott, J. M. 1974. Sediment discharge in the Trinity River Basin, California. Water Resources Investigations. 62 pp. (NTIS)

Long-term total sediment discharge of the Trinity River and selected tributaries is estimated. Water discharge data for the period 1912-1970 and sediment data collected between 1955 and 1970 were used to evaluate trends and relations between sediment discharge (suspended and bedload) and water discharge. The hydraulic and sediment transport characteristics of many of the streams in the basin were significantly altered by the December 1964 flood. Data indicate that the depth and velocity of streams changed drastically; and that for equal magnitudes of streamflow. Suspended sediment discharges after the 1964 flood were several times larger than before the flood. The long-term average annual sediment discharge of the Trinity River near Hoopa is estimated to be 3,120,000 tons (2,830,000 metric tons). The percentage of clay, silt, and sand or coarser material at this station is estimated to be 20, 32, and 48 percent. Bedload discharge is estimated to be 19 percent of the total sediment discharge.

Koski, K V. 1966. The survival of coho salmon (*Onchorhynchus kisutch*) from egg deposition to emergence in three Oregon coastal streams. M.S. Thesis. Ore. State Univ., Corvallis. 84 pp. (OR)

Survival of coho salmon from egg deposition to emergence was studied in three coastal streams in Oregon from September 1963 until September 1964. Adult coho salmon were captured, tagged, and measured as they entered the streams. Redds of specific females were located and the number of deposited eggs was estimated. A trap that captured the emerging fry was installed on each of these redds and the survival of emerging fry evaluated in terms of gravel composition, gravel permeability, dissolved oxygen, and gravel stability. Size of the parent female and the environmental factors were examined in relation to size and robustness of the emergent fry.

Egg deposition of the spawning coho salmon was estimated from a regression equation based on weight and egg number of coho from a nearby stream. The fry trap, constructed of nylon netting, was installed as a cap over the redd, and the edges were buried eight inches in the gravel. The concentration of dissolved oxygen in the intragravel water and the gravel permeability were sampled by means of a standpipe placed in each of the redds. Three samples of gravel were obtained from each redd and separated through a series of sieves. The volume retained by each sieve was expressed as a percentage of the total sample. Gravel erosion index stations were established in each of the streams to measure the relative amount of gravel movement.

Mean survival to emergence from 21 redds in the streams was 27.1 percent. Fry in Deep Creek had the highest survival (54.4 percent), followed by Needle Branch (25.1 percent), and Flynn Creek (13.6 percent). The number of emerging fry ranged from 0 to 2, 061. A mean of 110 days was required for the first emergence from the redds. Mean length of the emergence period for an individual redd was 30, 35, and 39 days for redds on Deer Creek, Needle Branch, and Flynn Creek, respectively. Length of the emergence period appeared to be related to the amount of fine sediments in the redd. Peak emergence from each redd occurred eight to ten days following the first emergence.

The size composition of the gravel was the only factor which showed a statistically significant correlation with survival to emergence. The percentage of fine sediments smaller than 3.327 millimeters had the highest correlation (correlation coefficient r = -0.69) of all size groupings tested. In each stream the percentage of fine sediments was inversely related to survival. Both gravel permeability and dissolved oxygen concentration were directly related to survival, but neither correlation coefficient (r = 0.36 and 0.24, respectively) was statistically significant at the five percent level, probably because of the interrelationships of several environmental factors affecting survival. Gravel movement was extensive in some areas of the streams.

Size and robustness of the emerging fry decreased throughout the emergence period in each of the redds examined. Both permeability of the gravel and weight of the female parent were directly related to the weight of the emergent fry.

Koski, K V. 1972. Effect of Sediment on Fish Resources. Paper presented at Wash. State Dep. Nat. Resources Mgmt. Seminar, Lake Limerick, Wash. 36 pp. (GS)

The effects of sediment on aquatic organisms are discussed. Specific areas of discussion are: (1) freshwater requirements of salmonids, (2) general effects of sediment on fish, (3) effects of sediment on the reproduction of salmonids, (4) the harmful threshold of sediment, (5) effects of sediment on natural populations of fish, and (6) effects of logging on sediment production. An extensive bibliography is included.

Koski, K V. 1974. Bibliography on the forest and aquatic resource relationships in southeastern Alaska. For. Sci. Lab., Juneau, Alaska. 26 pp. (OR)

This bibliography is a list of references concerning primarily the effects of logging on the salmon resources of southeast Alaska. The majority of items are in the form of unpublished reports, correspondence, and notes. Its purpose is to organize the variety of literature on this subject into one central library where field personnel can readily obtain and use it. A considerable amount of effort is never published or even applied, and this type of listing could help keep us informed of past work and of obvious gaps in our knowledge. The use of this listing in conjunction with the excellent "Annotated bibliography of the effects of logging on fish of the western United States and Canada," by Dave R. Gibbons and Ernest O. Salo (General Technical Report PNW-10, 1973) should provide a working foundation for managers and researchers alike.

Koski, K V. 1975. The survival and fitness of two stocks of chum salmon (*Oncorhynchus keta*) from egg deposition to emergence in a controlled stream environment at Big Beef Creek. Ph.D. Dissertation. Univ. Wash., Seattle. 212 pp. (OR)

A controlled-flow stream channel 183 m long x 3 m wide was designed and built at the University of Washington's Big Beef Creek Fish Research Station in order that specific variables important in the reproduction of chum salmon (*Oncorhynchus keta*) could be manipulated and tested. The experimental design of the channel allowed for replication of experiments within any one year and repetition in following years. Adult chum salmon from early and late spawning migrations were captured at the mouth of Big Beef Creek, measured, individually marked, and allowed to spawn naturally within the prescribed sections of the channel at a specified density. Characteristics of the parental stock of spawners, composition of the gravel used for redd construction, concentration of dissolved oxygen in the intragravel water, and temperature of the water were evaluated with respect to the rate of survival from egg deposition to emergence and fitness of the emergent fry. The emerging fry were trapped and enumerated daily from each of the 24 sections of the channel. The fry were routinely sampled for length, weight, stage of development, lipid content, and detailed morphometric measurements.

The abiotic variables, water temperature, water level and discharge, dissolved oxygen, and gravel composition, were monitored regularly. Predictive equations for the fecundity and egg size of chum salmon were developed from samples of the populations in order that estimates of the egg number and egg size deposited by individual females could be made. Laboratory experiments were performed to determine the importance of material (i.e., egg size) and paternal (i.e., male size) influences on the size of the fry up to the time of complete absorption of the yolk.

An array of ecological adaptations was disclosed which allowed for the continuity of the genetic differences between the early and late stocks of chum salmon in Big Beef Creek. The adaptations in the adult chums included the time of spawning, size and age of the spawners, fecundity, and egg size; adaptations in the emergent fry included timing of emergence, stage of development, and size and robustness. Criteria for describing fry fitness were based on the preceding adaptations of the emergent fry. Equations were developed which described the effects of low concentrations of dissolved oxygen and increased levels of fine sediment on survival to emergence and fitness of chum salmon fry. A quantitative estimate of the effects of increased sediment indicated that survival to emergence decreased 1.26 percent for each 1.0 percent increment in sand. A decrease in fry fitness was directly related to low dissolved oxygen and high percentages of sand in the spawning gravel. A selective mortality against fry of a larger size was also suggested in gravel containing high amounts of sand. A reduction in fry fitness may have pronounced effects on survival following emergence. Much of the observed variability in marine survival may be accounted for by a knowledge of the rate of survival to emergence and fry fitness.

Kramer, J. R., and G. K. Rodgers. 1968. Natural processes and water quality control. Pages 419-431 *in* Proc. Great Lakes Water Resources Conf., June 24-26, 1968. ASCE and Eng. Inst. Canada. (OR)

Natural processes are the basis upon which long-range management plans must be based. Natural processes are dynamic, and some processes are irreversible. Generally irreversibility (nonequilibrium) becomes more severe as pollution increases.

The Great Lakes approach small oceans in size, and each Great Lakes has its unique characteristic with regard to assimilation of constituents. This is expressed in varying size (particularly depth), bottom sediment, current pattern, and emptying rate.

Deviation from time independent equilibrium for major inorganic ions and first order rate reactions for biological species can be used to diagnose degradation factors. Excess carbon dioxide, oxygen deficiency, excess phosphate (relative to saturation with hydroxyapatite) are three measures of water quality. Rates of cell division under continuously favorable conditions (nutrients, temperature, low turbidity) predict bloom conditions in cycles of one week.

Attempts to maintain conditions near reversibility are important relative to obtaining high quality water over long periods of time. Engineering design must incorporate new technology based upon knowledge of natural processes in order to obtain this condition.

Krygier, J. T. 1971. Studies on the effects of watershed practices on streams. USEPA Grant No. 13010EGA. Ore. State Univ. 173 pp. (OR)

The purpose of the substudy was to describe the long-term effects of clearcutting timber on two small streams in the Oregon Coast Range. One watershed contained three small clearcuts; the edges of the clearcuts were generally 100 feet from the main stream, thus providing shade. The second watershed was completely clearcut and most of the main stream was exposed. A third watershed and some uncut subwatersheds were retained as uncut controls. The three watersheds range from 175 to 750 acres. The diurnal temperature regime was not altered after logging on the watershed with three small clearcuts. The fully clearcut watershed had a maximum diurnal change in temperature of 8°F before it was logged, but 28°F after logging.

The maximum temperatures recorded in the two years after logging on the patchcut watershed was 60 and 61.5°F--little different from the control. The maximum temperature on the fully exposed stream after logging was 85°F, a 28°F increase. All temperature regimes had a trend toward the prelogging condition in subsequent years.

The principal conclusion was that temperature change in these small streams is associated with the degree of exposure to sunlight. The changes in temperature lessen as the area along the stream revegetates.

Streamside strips will minimize temperature change after logging. The decision to leave such strips depends on timber and aquatic values, the degree of temperature change anticipated if timber is removed, and re-establishment rate of streamside vegetation.

Langlois, T. H. 1941. Two processes operating for the reduction in abundance or elimination of fish species from certain types of water areas. Trans. Sixth N. Am. Wildl. Conf. Pp. 189-201. (OR)

1. Two processes both operating on fishes by changing the conditions under which they live are described as leading to reduction in abundance or elimination of species from certain types of water areas.

2. The land-use practices of the past few decades in those areas where the streams tributary to Lake Erie arise have led to erosion and increased the silt loads in those streams. That has, in turn, increased turbidity and brought about the elimination of the dense aquatic meadows that once prevailed in the southwest shore bays.

3. Silt has also been carried into the lake and deposited over the hard bottoms around the islands. Hence the fish species which require clean hard bottom for the successful incubation of their eggs, including the ciscoes and whitefishes, have been greatly reduced in abundace and appear to be approaching extinction.

4. Those which need vegetational areas for spawning and early growth, as the yellow perch, are also showing diminishing numbers.

5. The fishes that require clear water for the production of successful year groups now are characterized by dominant year groups, spawned during drought years when tributary streams were low but clear.

6. Those which tolerate turbid water, as the sauger, sheepshead, catfishes, and carp are thriving under present conditions and in no danger of depletion.

7. The changes in the progress of small isolated glacial lakes towards extinction are of such nature as to modify the condition required by the fish species for successful breeding.

8. Those of most significance are changes in bottom, kind and abundance of vegetation, and depth of water.

9. Modifications of breeding conditions by silting and vegetating offer sufficient explanation for the elimination of all fish species requiring access to clean bottom for breeding.

10. When all bottom breeding species have been eliminated there remain two or three species that lay their eggs on submerged vegetation.

11. Reduced oxygen content is probably the factor causing elimination of these last few species.

Lantz, R. L. 1967. An ecological study of the effects of logging on salmonids. 47th Annu. Conf., West. Assoc., State Game Fish Comm., Proc. 1967:323-335. (GS)

The Alsea watershed study and some of its findings concerning the effects of logging on fish populations are outlined. The objective of the study was to evaluate and compare the effects of two patterns of timber harvesting. The study included an examination of fish population, stream environment, intragravel environment on salmonid survival to emergence, streamflow, stream temperature, and suspended sediment.

Lantz, R. L. 1970. Effects of logging on aquatic resources. Pages 13-16 *in* H. J. Rayner, H. J. Campbell, and W. C. Lightfoot, eds. Progress in Game and Sport Fishery Research. Rep. Res. Div., Ore. State Univ., Corvallis. (EPA)

An Oregon State University study on the Alsea watershed in Oregon is summarized. Primary changes observed on the aquatic environment due to logging were an increase in stream temperature, a decrease in dissolved oxygen levels in surface waters during summer when logging debris was present, a decrease in intragravel dissolved oxygen levels and in the permeability of the intragravel environment when salmon embryos were present, an increase in suspended sediments, and a decrease in the cutthroat trout population.

Lantz, R. L. 1971. Guidelines for stream protection in logging operations. Ore. State Game Comm. 29 pp. (OR)

The resources produced in a watershed are interdependent and the activities of man in utilizing one resource can affect others.

Various agencies have the responsibility for these resources. Coordination and a factual basis for management are necessary if benefits are to be realized.

This publication is an attempt to outline a practical basis for the management of Oregon's coastal watersheds for the continued production of timber, fish, and high-quality water. Its main thrust, based on research results, is that forestry and fishery management need not conflict. By protecting streamside vegetation and minimizing sources of sedimentation through careful planning, these resources can be produced at the same time in the same watersheds for the benefit of man. Our agencies are working together to achieve that goal.

Laronne, J. B., and M. A. Carson. 1976. Interrelationships between bed morphology and bed-material transport for a small, gravel-bed channel. Sedimentology 23:67-85. (OR)

Bed conditions (micro-relief, textural associations and packing structural arrangements) in the gravel-bed channel of Seale's Brook are shown to be closely interrelated; various categories are identified and related to mode of bed material transport and deposition.

Entrainment of bed material, commonly treated as a simple function of particle weight and channel hydraulics, is also shown to be strongly affected by varying and variable bed conditions. In particular, the classic concept of competence appears to be of restricted utility in such channels; resistance of bed material to fluid drag and to particle impact is augmented, over large parts of the channel bed, by its interlocking structure, made possible by the wide range in particle calibre, and by the characteristic disc and blade shapes of the slate debris.

Particle mobility, as indicated by distance of travel of labelled bed material, is only partly a function of particle weight; indeed, although particle mobility decreases from small pebbles to large cobbles, it also decreases for the finest bed material (very small pebbles). This appears to be explicable, partly in terms of the ease of entrainment (and duration of travel), and partly in relation to the ease of transport of material over an uneven channel bed surface. Particle mobility is greatest for material in open and infilled structures and smallest for sediment in tight structural arrangements. Local bed slope also exerts an influence on the probability of particle entrainment and on particle mobility.

The findings emphasize the need for combining sedimentological and engineering approaches to bed material transport in coarse-bedded channels, and at the same time, illustrate some of the reasons for the existence of indeterminacy in the modelling of bed-material transporting processes.

Larson, A. G., D. D. Wooldridge, and A. R. Wald. 1976. Turbidity-suspended sediment relations in forest streams of the western Olympics. Final Rep.--Part II. Coll. For. Resources, Univ. Wash., Seattle. 21 pp. (OR)

Suspended sediment, not turbidity *per se*, is the water quality parameter of importance. This paper reports results of investigation of variability associated with turbidity measurements as estimates of quantities of suspended sediment. It is part of a study of quantities sediment transported in forested watersheds under varying intensities of forest management.

Leonard, J. W. 1962. Environmental requirements of Ephemeroptera. Pages 110-117 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft. Sanit. Eng. Cent. (OR)

Much more is known about the distribution of Ephemeroptera with regard to the physical characteristics of the environment than about their reaction to variations in water chemistry, especially chemical variations introducted by human activity. While general ecological requirements of the common species are known, conditions of microhabitat have rarely been investigated; for many described species the immature stages are themselves unknown.

In North America, a considerable part of our knowledge of mayfly ecology has been gained in connection with studies of feeding habits and requirements of fishes, especially trout, and with attempts to develop and evaluate methods of environmental manipulation to improve fisheries.

In certain parts of the country, studies of nymphal distribution made 3 or 4 decades ago have made it possible to evaluate the effect of both gradual and sudden ecological changes. In a few instances recovery of a mayfly fauna decimated by natural catastrophe, or by man-made pollution, subsequently brought under control, has been followed.

An attempt is made to outline the status of our knowledge of mayfly requirements to date and to point out problems in particular need of study.

Leudtke, R. J. F. J. Watts, M. A. Brusven, and T. E. Roberts. 1973. Physical and biological rehabilitation of a stream. Pages 259-267 *in* Hydraulic Engineering and the Environment. Proc. 21st Annu. Hydraul. Div. Specialty Conf., Montana State Univ., Bozeman. (OR)

There were three basic objectives of this study:

1. Conduct a biological and physical inventory of problem reaches in a silted stream and to develop criteria for quantifying changes in bed material as it relates to its suitability for aquatic life,

2. Evaluate the effectiveness and suitability of log drop structures and gabion constrictors for the rehabilitation of problem sites, and

3. Examine in a qualitative way the seasonal transport of sediment in different reaches of the stream.

Aquatic insects were used as an indicator organism because their numbers change rapidly in response to stream modifications.

Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Amer. Fish. Soc. 98(1):14-19. (OR)

The relationship between fish populations and physical parameters of pools was studied in Little Prickly Pear Creek, Montana, during the summers of 1965 and 1966. The pools were mapped and their fish populations sampled. Surface area, volume, depth, current velocity, and cover accounted for 70 to 77 percent of the variation in numbers of trout over 6.9 inches total length. Most of the variation was the result of differences in current velocity and cover. Cover was the most important factor for brown trout, and current velocity for rainbow trout. The density of all trout per unit area of pool surface and cover increased significantly as current velocity became greater. Deep-slow pools with extensive cover had the most stable trout populations with brown trout showing greater stability than rainbow trout. The importance of cover to trout is discussed in terms of security and photonegative response and current velocity in terms of space-food relationships.

McCrimmon, H. R. 1954. Stream studies on planted Atlantic salmon. J. Fish. Res. Board Can. 11(4):362-403. (GS)

This is an evaluation of the survival and distribution of Atlantic salmon fry planted in a small stream tributary to Lake Ontario. Included is an examination of some of the factors affecting the survival of these fry. The influence of sedimentation on survival was studied in detail.

When the correlation of salmon survival with brook trout predation was analyzed further, it was found that the amount of available shelter which the stream offered the fry was most important in determining the survival or death of the planted fish.

It has been shown in a previous section that the shelter offered by shallow gravelly riffle area was the only satisfactory habitat for the survival of planted fry in all streams. In the general description of the relative extent of sedimentation over the stream system, the criterion employed was the degree to which these gravelly riffle areas have become sedimented. Areas typed as "unsedimented" were those in which the spaces around the gravel and rubble were not filled in by sediment and hence offered the shelter required by the planted fry. The degree of bottom sedimentation played an important part in influencing the survival and distribution of the planted salmon.

It was shown that the survival of the small fry in the pools was low, largely because the absence of suitable shelter for the young salmon resulted in predation by certain species of fish. This lack of shelter was directly caused by the deposition of sediment in the pools sufficiently great to cover generally the gravel and rubble, and fill the spaces around stones, boulders, logs and the like, to an extent that they could not be utilized by the fry.

Survival studies showed an average percentage survival for underyearling salmon . . . of 23.4 percent in comparison to a survival of only 2.2 percent in an area in which riffle sedimentation was the heaviest observed in the part of the stream system planted with salmon.

McNeil, W. J. 1962. Variations in the dissolved oxygen content of intragravel water in four spawning streams of southeastern Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep., Fish. No. 402. 15 pp. (OR)

Inexpensive equipment for sampling intragravel water for dissolved oxygen is described. Water samples were withdrawn from plastic standpipes driven into the streambed. Dissolved oxygen values representative of points sampled were obtained from 30-ml samples of water taken about 24 hours after standpipes were placed.

Fourfold seasonal and yearly changes in dissolved oxygen levels were observed. Spatial differences in dissolved oxygen levels were greatest when discharge was low and temperature was high.

For routine measurement of dissolved oxygen level random sampling was tried and found to be satisfactory.

McNeil, W. J. 1963. Quality of the spawning bed as it relates to survival and growth of pink salmon embryos and alevins and time of fry emergence. Bur. Comm. Fish., U.S. Fish Wildl. Serv., Auke Bay, Alaska (typed manuscript, illustrated). 22 pp. (OR)

Growth, development, and survival of embryos and alevins of salmonid fishes are affected by the availability of dissolved oxygen in spawning beds. The oxygen supply rate to an embryo or alevin is a function of dissolved oxygen content and apparent velocity of intragravel water.

Oxidizing organic detritus, interchange between stream and intragravel water, and permeability of bottom materials exert a significant influence on the amount of oxygen made available to embryos and alevins. Growth and survival of pink salmon (*Oncorhynchus gorbuscha*) embryos and alevins in a small southeastern Alaska stream were found to be related to these environmental attributes. Evidence was also obtained that fry emergence was delayed where environmental factors were most likely to cause occurrence of oxygen stress during development.

McNeil, W. J. 1964. Environmental factors affecting survival of young salmon in spawning beds and their possible relation to logging. U.S. Fish Wildl. Serv., Bur. Comm. Fish., Rep. 64-1 (manuscript). Auke Bay Biol. Lab., Auke Bay, Alaska. 25 pp. (GS)

In this report, an attempt has been made to review some of the factors influencing survival of salmon embryos and alevins which conceivably may be influenced by logging. The review has not been exhaustive, but an attempt has been made to include the more pertinent recent work which has come to the author's attention. It is possible to make some conclusions on the basis of this review.

Results of field studies have revealed that extrinsic environmental factors have an important bearing on the survival of young salmon in spawning beds. The data indicate that increased mortality may occur during periods of minimum and maximum flow of streams, when debris shifts position in stream channels and when permeability of spawning beds is reduced by the presence of fine particulate matter. It is conceivable that logging could exert both harmful and beneficial influence on young salmon in spawning beds. Harmful effects might include increased maximum flows of streams, more debris in stream channels, and more settleable solids transported into spawning streams. A beneficial effect might result should logging cause the minimum flows of streams in southeastern Alaska to increase. It is apparent that the addition of silt and debris to streams should be avoided and the stability of stream banks should be preserved whenever possible.

Solution of the salmon-logging problem lies ultimately in the economic development of watersheds and streams for the benefit of both resources. In this regard, some initial efforts have been made on improvement of natural spawning beds in Alaska . . . and more work is planned or underway. But even in the area of spawning bed improvement there is a great need to obtain a more detailed understanding of the biological and physical factors that control fry production from spawning beds. Hence, the natural processes that control fry production from salmon spawning beds must be well understood before a satisfactory evaluation or solution of the salmon-logging problem can be achieved.

McNeil, W. J. 1966. Effect of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish Wildl. Serv., Fish. Bull. 65(2):495-523. (OR)

Mortality of 5 brood years of pink salmon, *Oncorhynus gorbuscha*, and chum salmon, *O. keta*, in spawning beds of three southeastern Alaska streams was studied. Eggs and larvae were sampled periodically, and mortality was associated with certain environmental factors: The supply of dissolved oxygen, the ability of spawning beds, and freezing.

Total mortality between spawning and fry emergence typically varied between 75 and 99 percent in the study areas. High mortality occurred during low and high stream discharge and freezing air temperatures. Mortalities ranging from 60 to 90 percent of deposited eggs occurred in association with low dissolved oxygen levels during and after the spawning period. Movement of gravel in certain instances was associated with the removal of 50 to 90 percent of eggs and larvae present in spawning beds. Freezing caused up to 65 percent mortality of eggs and larvae in one stream.

Low dissolved oxygen levels occurred once in 5 years. This occurrence was associated with unusually low water during spawning in late summer. Mortality during periods of heavy precipitation was highly variable. In one instance, a 90-percent mortality occurred where wood debris was deposited within the high water channel. Wood debris floating over spawning beds was not damaging to eggs and larvae. There were several instances where mortality estimated at almost 50 percent occurred with no evidence that deposited wood debris shifted position. High mortality from freezing occurred only in the stream having the lowest minimum discharge.

McNeil, W. J. 1968. Effect of streamflow on survival of pink and chum salmon in spawning beds. Pages 96-114 *in* Richard T. Myren, ed. Logging and Salmon. Proc. Forum Am. Inst. Fish Res. Biol., Alaska Dist., Juneau, Alaska. (GS)

Studies conducted in southeast Alaska revealed the following:

1. Low streamflow in summer causes low levels of dissolved oxygen in intragravel water and high mortality of pink and chum salmon spawn.

2. Freezing can cause high mortality of pink and chum salmon spawn where streamflow fluctuates drastically. Spawn in streams with relatively stable streamflow which caried less than 100-fold between average daily minimum and maximum discharge experienced low mortality in cold winters.

3. Eggs and alevins of pink and chum salmon are highly vulnerable to dislodgment from spawning beds during high streamflow. The stranding of debris on spawning beds increases gravel movement and mortality.

4. Increased high streamflow and addition of debris to stream channels from logging would be harmful to pink and chum salmon. Increased low streamflow would be beneficial.

McNeil, W. J. 1969. Survival of pink and chum salmon eggs and alevins. Pages 101-117 *in* T. G. Northcote, ed. Symposium on Salmon and Trout in Streams. Univ. Brit. Columbia, Vancouver. (OR)

The production of pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon fry is controlled by density-dependent mortality. Production from Sashin Creek, Little Port Walter, southeastern Alaska, approaches a maximum of about 500 fry per $m^2$ of spawning ground at an egg deposition of 2,000 to 3,000 eggs per $m^2$. The production curve for Shashin Creek is dome-shaped.

Mortality from droughts, floods, or freezing temperatures may exceed 50 percent of the eggs and alevins in spawning gravels, but such mortality appears, for the most part, to be independent of population size. Superimposition of redds, on the other hand, causes density-dependent mortality; studies at Sashin Creek indicate that survival of eggs and alevins is higher when spawning is early than when it is late. Thus, a dome-shaped production curve in freshwater may result from replacement of more viable eggs from early spawners by less viable eggs from late spawners as the total number of spawners increases beyond the level where superimposition of redds becomes a frequent occurrence.

McNeil, W. J., and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish Wildl. Serv., Spec. Sci. Rep., Fish. No. 469. (OR)

The potential of a salmon spawning bed to produce fry is directly related to its permeability. The relationship between the coefficient of permeability and the fraction of bottom materials consisting of fine particles is inverse.

Field methods for measuring size composition of bottom materials in salmon spawning beds are described, and an empirical relationship between the fraction (by volume) of solids less than 0.833 mm minimum dimension and the coefficient of permeability of stream bottom materials is given. Size of bottom materials in streams utilized for spawning by pink salmon (*Oncorhynchus gorbuscha*) varied considerably. The more productive spawning streams had the more permeable spawning beds. Adult pink salmon caused the removal of finer particles from bottom materials during spawning. The evidence indicates that the fine particles removed consist largely of organic matter. Logging caused fine sands and silts to accrue to spawning beds. Flooding caused the removal of fine particles from spawning beds.

McNeil, W. J., P. Shapley, and D. E. Bevan. 1962. Effects of logging on pink salmon and spawning bed improvement. Pages 15-18 *in* Ted S. Y. Koo, ed. Res. Fish. Coll. Fish., Contrib. 139, Univ. Wash., Seattle. (GS)

A six-year study on factors causing egg and larval mortality in three southeastern coastal salmon streams was conducted. The summary includes a discussion on the interrelationships amoung spawners, quality of intragravel water, quality of spawning bed, and the effect of these factors on egg and larval mortality. Spawning bed improvement studies on two of the salmon streams were also conducted.

Maddock, T., Jr. 1973. A role of sediment transport in alluvial channels. ASCE, J. Hydraul. Div. 99(HY11):1915-1931. (OR)

In an earlier paper published in the Journal of the Hydraulics Division, the writer showed that once a critical amount of sediment is being moved by a laboratory alluvial channel, the velocity can be expressed as functions of slope and of size and composition of the moving sediment load. Depth is a redundant parameter. In the closure to the 1970 paper, the writer showed that laboratory data could be extrapolated to natural alluvial channels of varying magnitude. The same conclusion, that under certain conditions velocity is independent of depth in a stream transporting sediment, has been reached by Shen and Hung and Yang. However, there are two difficulties that are encountered. The first is the determination of the size of the moving sediment bed. It is the intention of this paper to present a method of describing this important parameter. The second problem, which is only described, is the determination of the conditions under which depth becomes redundant.

Another problem of stream behavior is fill and scour at cross sections. The effect of changing discharges and sediment concentrations in an alluvial channel of variable width will also be considered.

Martin, D. J. 1976. The effects of sediment and organic detritus on the production of benthic macroinvertebrates in four tributary streams of the Clearwater River, Washington. M.S. Thesis, Univ. Wash. 79 pp. (OR)

The effects of sediment and organic detritus on the production of benthic macroinvertebrates in four tributary streams of the Clearwater River, Washington, were investigated. Three streams receiving different logging intensities were compared to a stream unaffected by logging. Benthic fauna and substrate were collected monthly from September 1973 through September 1974 with a Neill cylinder. The fauna were identified and the substrate materials were partitioned into organic and inorganic particle categories. There were no significant ($P<0.05$) differences between benthic fauna standing crop in logging-affected and unaffected streams. Significant correlations between sediments, organic detritus and bottom fauna standing crop were present; however, these correlations were not consistent for each study stream.

The quantities of detritus measured in the study streams ranged from 8.8 $g/m^2$ to 44.2 $g/m^2$. Bottom samples collected from deeper in the substrate indicated that the Neill cylinder sampled less than 50 percent of the total quantity of detritus. The quantity of detritus was inversely related to particle size and there was a significant ($P<0.05$) positive correlation between quantity of organic detritus and sediment, for particle sizes <0.250 mm.

The annual aquatic insect production in the four study streams, estimated by the Hynes and Coleman method, ranged from 11.6225 $g/m^2$ to 20.5764 $g/m^2$. The scraper trophic category contributed 29.8 to 51.4 percent of the total production, the predators contributed 18 to 29.2 percent of the production, and the remaining production was contributed by shredders, collectors and chironomids. The production estimates were underestimated by four to eight times based on back calculations from fish production.

Mason, J. C. 1969. Hypoaxial stress prior to emergence and competition among coho salmon fry. J. Fish. Res. Board Can. 26:63-91. (OR)

Competiton among coho salmon fry in stream aquaria supplying natural drift was found to reflect the history of exposure of eggs and resulting fry to dissolved oxygen concentration prior to emergence. Size disparities induced by differential hypoaxial stress were amplified with time, and fry that had been exposed to the most severe hypoaxial conditions were most prone to emigrate. Most emigrants placed in an intially vacant, replicate system remained there, grew rapidly, and became as large as, or larger than, nonemigrants. Size of former emigrants reflected enhanced feeding opportunity due to less competition for food and space in the replicate system. Competition was referred more precisely to hypoxial history by using net production. A replicate population fed hatchery food provided a comparison. When exposed to the stream aquaria, this population substantiated the previous findings.

Diel cycles of activity and aggression peaked at dawn and dusk, and were related to competition for food and space. The ecological significance of the results is discussed with particular regard to competition for food and space, and the effect of a size-related social order that put smaller individuals at a disadvantage.

Meehan, W. R. 1971. Effects of gravel cleaning on bottom organisms in three southeast Alaska streams. Prog. Fish-Cult. 33(2):107-111. (EPA)

Sections of streambed in three southeast Alaska streams were cleaned by means of a mechanical "riffle sifter." Results indicate that invertebrate populations were reduced as a result of cleaning, but that they returned to pretreatment levels of abundance within a year after gravel cleaning.

Meehan, W. R. 1974. The forest ecosystems of southeast Alaska. 3. Fish Habitats. USDA For. Serv., Gen. Tech. Rep., PNW-15. Portland, Ore. 41 pp. (OR)

The effects of logging and associated activities on fish habitat in southeastern Alaska are discussed, and fish habitat research applicable to southeast Alaska is summarized. Requirements of salmonids for suitable spawning and rearing areas are presented. Factors associated with timber harvest which may influence these habitats are discussed in detail; e.g., sediment, stream temperature, streamflow, logging debris, and chemicals. Recommendations for further research are made.

Megahan, W. F. 1972. Logging, erosion, sedimentation--Are they dirty words? J. For. 70(7):403-407. (EPA)

Erosion and sedimentation are not dirty words. They are, in fact, natural phenomena that make the world go round. They proceed inexorably even in an undisturbed forest. In a small undisturbed watershed in Central Idaho, for example, the annual sediment production varies over a range of one order of magnitude, the average rate being about 390 foot$^3$/mile$^2$/year.

Considering the three factors; detachability, forces applied, and surface cover, the author feels that overall erosion hazard rating of a small increase for cutting plus skidding and a moderate to large increase for roads are realistic. Roads have a much greater effect per unit area of disturbance than do cutting and skidding.

The basic principles are summarized as: Timber harvesting, including cutting plus skidding, and especially roads, do tend to accelerate erosion and sedimentation. Accelerated erosion and sedimentation may cause either onsite or offsite damage, or both. They are usually, but not necessarily, cause and effect phenomena. Erosion hazards vary greatly with location, even within small areas. Roads create a disproportionate share of the problems, probably greater than 90 percent in most areas. Surface erosion rates are highest immediately after construction, and tend to decrease rapidly with time. Under certain conditions, mass erosion problems can occur from timber removal alone but are much more likely to occur on roads over a considerably broader scale of site conditions. The care taken in conducting timber harvest can have considerable influence on the impact that results. Accelerated erosion and sedimentation can, and often do, continue after logging operation ends.

The general guidelines for minimizing erosion and sedimentation problems are: 1) stratifying the land according to erosion hazard. Plan and develop road access and timber sales accordingly; 2) minimizing roads by: a) proper sale planning and selection of the logging system; 3) using proper planning, execution, and follow-up procedures to assure erosion control.

Megahan, W. F., and W. J. Kidd. 1972. Effects of logging and logging roads on erosion and sediment production from steep terrain. J. For. 70(3):136-141. (OR)

Effects of logging road construction on sediment production rates were studied on small, ephemeral drainages in the Idaho batholith, a large area of granite rock characterized by steep slopes and highly erodible soils. For the six-year study period, about 30 percent of the total accelerated sediment production from roads was caused by surface erosion; the remainder resulted from mass erosion. Surface erosion on roads decreased rapidly with time after extremely high initial rates. A mass failure of a road fill slope occurred about four years after construction, when surface erosion had fallen to a low rate. The sediment production rate attributed to erosion within the area disturbed by road construction averaged 770 times greater (220 because of surface erosion and 550 because of mass erosion) than that for similar, undisturbed lands in the vicinity.

Results suggest three guides to use in the control of surface erosion on roads and subsequent downslope sediment movement in the Idaho batholith: a) Apply erosion control measures immediately after road construction for maximum effectiveness; b) ensure that treatments protect the soil surface until vegetation becomes established; c) take advantage of downslope barriers (logs, branches, etc.) to effectively delay and reduce the downslope movement of sediment.

Merrell, T. R. 1951. Stream improvement as conducted in Oregon on the Clatskanie River and tributaries. Fish. Comm. Ore., Res. Briefs 3:41-47. (GS)

All evidence seems to point to the fact that drastic clearance of logs and debris from salmon streams increases accessibility and at least does not damage productivity. Although the stream bottom was greatly disturbed, in less than a year natural conditions had largely restored themselves. About 15 additional miles of stream were made readily available to spawning salmonids.

It is believed that due to improvements made the Clatskanie and its tributaries are at present capable of providing spawning and rearing facilities for large numbers of silver salmon and steelhead trout.

Milhous, R. T. 1972. Sediment transport in a gravel-bottomed stream. Ph.D. Dissertation. Ore. State Univ. (OR)

Sediment transport in a gravel-bottomed stream located in the Oregon Coast Range was studied to determine the effects of a single layer of large particles (the armour layer) located at the surface of the bed material. The bed load transport system was studied jointly with suspended sediment transport to understand the total transport system. The bed load was sampled using a vortex trough in the stream bed which transported the bed load material into a sampling pit adjacent to the stream.

It was found that the armour layer controls the bed load transport system by preventing sand and finer material from the bed from being entrained in the flow unless the armouring particles are first moved. The bed load of an armoured stream can be calculated using the simplified Einstein bed load function with a representative diameter for the stability parameter equal to the particle size of armouring material at which 35 percent of the material is finer ($D_{35}$ size) and a representative size for the transport parameter equal to the media size of bed material below the armour layer. The critical discharge for disturbing the armour layer is related to a size equal to 69 percent of the $D_{65}$ size. The critical shear stress of the armouring material is at a minimum for a particle equal to the 0.69 $D_{65}$ size. Smaller particles are hidden in the armour layer and larger particles are heavier than the critical particle.

From observation of the maximum size of particles transported for various stream discharges, the Shields parameter was found to be 0.025 for a rough bed and for a transport rate of very nearly zero.

The suspended sediment transport system was found to be partially related to the past history of the stream because the past history of flows and sediment load controls the ability of the armour layer to remove sand and finer material from the water in the stream or to supply these smaller particles to the water.

Both the bed load and suspended load of Oak Creek are quite variable when the discharge is below the critical discharge of the armour layer.

Milhous, R. T. 1973. Sediment transport system in a gravel-bottomed stream. Pages 293-303 *in* Hydraulic Engineering and the Environment. Proc. 21st Annu. Hydraul. Div. Spec. Conf. Montana State Univ., Aug. 15-17, 1973. (OR)

The sediment transport system in a coarse-bedded mountain stream in the Oregon Coast Range has been studied for three years. The streambed is nonhomogenous, with an armour layer of larger particles on top of finer material. A conceptual model of the sediment transport system in a armoured stream was developed to better describe the suspended sediment component of the total transport system. The use of existing bed load calculation procedures for determining the bed load in an armoured stream was examined. It was found that there is an important interaction between the armour layer and the movement of material as bed load and as suspended load. Use of the existing bed load equations is made quite tenuous when an armour layer exists. The armour layer is the single most important factor in limiting the availability of streambed sediment and in controlling the relationship of streamflow and sediment load in a gravel-bottomed stream. The armour layer controls the sediment transport system by regulating the reservoir of sand and finer particles in the streambed and by protecting the bed material from entrainment in the flow. At high flows the armour layer controls the rate of release of material to the bed load and suspended load of the stream; at intermediate flows it prevents fine sand in the bed from being entrained in the flow; at low flows it filters out fine material. The behavior of the "fines" reservoir for different portions of the runoff hydrograph is demonstrated to regulate the suspended load of the stream.

Miller, C. R., and A. J. Bowie. 1965. Sediment sampling--instrumentation and techniques. Trans. Am. Soc. Agr. Engr. 8(2):267-270. (OR)

The various instruments and techniques currently employed by the USDA Sedimentation Laboratory to sample sediment discharge have been described. Although improvements in existing sampling equipment and techniques are constantly being made and new devices for sediment sampling and concentration sensing are being developed, major problems associated with accurate determination of total sediment movement and measurement of sediment discharge on rapid rising streams and at remote locations, remain unsolved.

A variety of methods to improve and automate sediment sampling are currently under investigation by the Federal Inter-Agency Sedimentation Project. The USDA Sedimentation Laboratory continues its efforts to improve sediment-sampling techniques and procedures including the adaptation of electronic, ultrasonic, photoelectric, and capacitance processes. At present the radioisotope means of sediment concentration sensing and the development of various pumping-type samplers seem to offer the best possibility for improved sediment discharge determinations. It is also expected that continuing research will provide guides and methods for combining field sediment-sampling results with stream hydraulics and sediment characteristics in the development of methodology for determining total sediment discharge.

Moore, E. 1937. The effect of silting on the productivity of waters. Trans. Second N. Am. Wildl. Conf. Pp. 658-661.

Silt transport in streams and subsequent deposition in lakes, ponds, and reservoirs are natural occurrences common to all watersheds. However, where these processes are extreme, they can severely limit the use span of man-made impoundments, and restrict fish populations and food supplies. Heavy deposits of silt exclude fish, bury food organisms and reduce transparency depth necessary for phytoplankton development.

Small attention has been afforded the siltation problem. Greater effort needs to be directed toward its prevention.

Moring, J. R. 1975a. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part I--Biological studies. Ore. Dep. Fish Wildl., Fish. Res. Rep., No. 9. 66 pp. (OR)

Three small tributaries of Drift Creek, tributary to the Alsea River, Oregon, were monitored during a 15-year logging study, 1959-1973. One watershed (Needle Branch) was clearcut without buffer strips. A second (Deer Creek) was clearcut in patches with buffer strips and the third (Flynn Creek) was unlogged, and served as a control. This report covers the biological results of the study, and outlines those components that were altered as a result of logging activities (road construction, yarding, felling). Cutthroat trout populations were severely depressed after logging in Needle Branch, and remained low during the eight-year post-logging period. The timing of downstream migration of cutthroat juveniles in the stream was altered for two years after debris clearance and slash burning in Needle Branch. Coho salmon were less affected by logging, but average lengths and weights and condition factors were low in juveniles in Needle Branch the summer after logging. Those fish that were fry and fingerlings in Needle Branch at the time of logging had lower fecundities when they returned as adults. Coho biomass and net production rates increased in the streams of the two logged watersheds following logging. The two youngest year classes of reticulate sculpins were almost completely destroyed by logging in Needle Branch and there was a decline in numbers of adult western brook lampreys in Needle Branch in post-logging years. Additional biological data on fish populations are presented.

Moring, J. R. 1975b. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part II--Changes in environmental conditions. Ore. Dep. Fish Wildl., Fish. Res. Rep., No. 9. 39 pp. (OR)

Three small tributaries of the Alsea River, Oregon, were monitored during a 15-year study, 1959-1973. One watershed (Needle Branch) was clearcut without buffer strips. The second (Deer Creek) was clearcut in patches with buffer strips. The third (Flynn Creek) was unlogged, and served as a control. This portion covers the environmental results of the study, and outlines those components that were altered as a result of logging activities (road construction, yarding, felling).

Water temperature maxima and ranges were significantly increased in Needle Branch by the removal of riparian, protective vegetation during clearcutting. Maximum temperatures reached 26.1°C near the mouth, and 29.5°C at a point upstream in summer 1967. Temperatures increased 12.7°C over the pre-logging average in June, and a 15.6°C maximum diurnal fluctuation was measured in 1967. Surface dissolved oxygen lvels dropped to 2.5 mg/liter in the summer of logging, and intragravel levels decreased to a mean of 1.3 mg/liter the same summer. There was a pronounced decrease in intragravel dissolved oxygen during the first winter when salmonid eggs were developing in the gravel. Mean monthly streamflow increased by 26.9 percent in Needle Branch after logging. There was a 205.3 percent increase in suspended sediments in Needle Branch, and a 53.3 percent increase in Deer Creek following road construction. Permeability of the gravel in Needle Branch was depressed from logging, and remained so during the post-logging years.

Moring, J. R. 1975c. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part III--Discussion and Recommendations. Ore. Dep. Fish Wildl., Fish. Res. Rep. No. 9. 24 pp. (OR)

On the basis of the results of the Alsea Watershed Study, detailed in Parts I and II and outlined herein, recommendations are offered for logging operations in areas with small headwater streams. The use of buffer strips is supported, along with the careful design, construction, and maintenance of logging roads. Felling of timber should be away from the stream. No yarding of logs ought to take place in or across the stream. Logging debris must be removed from the stream as soon after cutting as possible, but some debris can remain in the stream. State fisheries agencies should have input into proposed cutting plans.

Moring, J. R., and R. L. Lantz. 1974. Immediate effects of logging on the freshwater environment of salmonids. Fed. Aid Prog. Rep. Fish., AFS-58. 101 pp. (OR)

Twelve western Oregon streams were studied in the summers of 1967-72 to assess the effects of several types of logging practices. Streams were studied one season prior to logging and one season after logging. Three general methods of logging were employed: Clearcutting without buffer strips, clearcutting with buffer strips, and road construction with partial thinning. All streams contained coho salmon (*Oncorhynchus* *kisutch*) and/or cutthroat trout (*Salmo clarki*). Steelhead trout (*S. gairdneri*) were present in four streams. Parameters measured included population estimates, condition factors, biomass, water temperature, surface and intragravel dissolved oxygen, streamflow, gravel composition, pH, and pool/riffle and spawning gravel estimates. Cutthroat trout populations declined following logging, while coho salmon populations were apparently little affected. The maximums and the ranges of temperatures increased in 10 of the streams. Minimum recorded intragravel and surface dissolved oxygen levels declined on the majority of streams. Gravel was less evenly distributed and composition was more variable in streams following logging. Streams with intact buffer strips suffered less gravel disruption. Streambed damage varied greatly amoung streams, and was generally related to the type of logging and the care taken by individual operators in yarding, falling, and road construction. The short-term approach used in this study is useful for spot analysis of physical and biological parameters. However, use of a long-term, case history approach is a more valid technique in the ultimate interpretation of results. The long-term Alsea Watershed Study provided indications of annual variation of some parameters that were useful in evaluating the results of this smaller, more diverse study. It is recommended that long-term studies be utilized whenever possible.

Mortensen, D. G., B. P. Snyder, and E. O. Salo. 1976. An analysis of the literature on the effects of dredging on juvenile salmonids. Spec. Rep. to Dep. Navy, Contract No. N-68248-76-C-0011. March 15, 1976. 37 pp.

This literature survey was conducted in an attempt to establish the tolerance levels of juvenile salmonids to various levels of suspended solids. Various possible direct and indirect effects of suspended sediments are discussed.

Mundie, J. H. 1971. Sampling benthos and substrate materials, down to 50 microns in size, in shallow streams. J. Fish. Res. Board Can. 28:849-860. (OR)

Streambed materials, both biotic and abiotic, in the size range 50 μ-ca 200 mm can be sampled unselectively, in shallow streams, with a simple inexpensive apparatus consisting of a box provided with an adjustable upstream inlet, and, downstream, two nets, one within the other. Collected materials are wet-sieved and the volumes of inorganic material passed by successively finer sieves are plotted as cumulative curves against a logarithmic size scale. Curves are given for materials from three contrasting habitats: A riffle, and pool, of a coastal stream, and an artificial spawning channel. Examples are also given of the densities, size distribution, and vertical stratification of invertebrates from these habitats. Applications of the method to studies on fish biology, invertebrate ecology, and geomorphology are indicated.

Narver, D. W. 1971. Effects of logging debris on fish production. Pages 100-111 *in* J. Morris, ed. Proc. of a Symposium on Forest Land Uses and Stream Environment. Ore. State Univ., Corvallis. (OR)

Stream salmonids (eight species of Pacific salmon, trout, and char) are discussed in relation to their environmental requirements and the possible impact of logging debris on their production. The emphasis is on small streams because of their great importance as nursery and spawning areas for certain species and because they may be more susceptible to damage than larger streams or rivers. Extensive use is made of pertinent literature. It is concluded that accumulations of logging debris in small streams can have serious consequences on the production of salmonid fishes.

National Environmental Research Center, Las Vegas, Nevada. Monitoring applications techniques. 1975. Nonpoint-Source Pollution in Surface Waters: Associated Problems and Investigative Techniques. Final Rep. 47 pp. (EPA)

The report briefly discusses the following: Nature and origin of nonpoint-source pollution; sources of nonpoint pollutants; prediction of nonpoint-source pollution; and nonpoint-source monitoring.

National Technical Advisory Committee to the Secretary of the Interior. 1968. Water quality criteria. Rep. Nat. Tech. Advisory Comm. to Secretary Interior. Fed. Water Poll. Control Admin. 234 pp. (OR)

This report of the National Technical Advisory Committee concerns criteria--a significant part of water quality standards. The Committee considered the water use criteria set forth in this report with objective of assisting the State and Federal agencies in setting and evaluating standards so they can meet water pollution abatement objectives.

The Committee was concerned about several issues relating to water quality standards for the control and abatement of water pollution. Foremost among these is the lack of adequate knowledge concerning many of the quality characteristics upon which criteria and, hence, standards should be based. The unknowns still outweigh the knowns. Complicating factors in setting standards are varying natural conditions affecting water quality, such as climate, geography, and geology of a specific location. The Committee does not want to be dogmatic in recommending these criteria. They are meant as guidelines only, to be used in conjunction with a thorough knowledge of local conditions. Further, it is anticipated that future research will provide considerable basis for refinements in the recommendations.

Neave, F. 1947. Natural propagation of chum salmon in a coastal stream. Fish. Res. Board Can., Prog. Rep. Pac. Coast Stn., No. 70. Pp. 20-21.

Very heavy losses can occur through physical conditions of the environment as well as through the actions of fish. The author suggests that remedial measures are feasible and desirable because of the high proportion of losses in pre-hatching stages. Suggestions included better distribution of eggs and the protection from extreme changes in water level and velocity.

Needham, P. R. 1948. Survival of trout in streams. Trans. Am. Fish. Soc. 77(1947):26-31. (OR)

In spite of extremely heavy expenditures for rearing of hatchery fish, the angling continues to decline. Millions of fish are wasted each year because of lack of facts on how best to utilize properly the product of hatcheries.

Survival studies have indicated that under natural conditions, wild brown trout suffer tremendous natural mortalities amounting to 85 percent in the first 18 months of life. Overwinter mortalities averaged 60 percent over a five-year period. Variable survival conditions rather than the number of young produced in any year, determine the number of fish that later reach catchable size.

Survival studies of hatchery-reared trout indicated heavier losses than with naturally spawned fish. Creel-census returns from a number of different waters are presented to support this fact.

The conclusion is reached that the angling public must be made aware of the basic economics of hatchery operation, its costs, successes, and failures in order that the field of fishery management again may move ahead.

Neilson, D. R. 1974. Sediment transport through high mountain streams of the Idaho batholith. M.S. Thesis. Univ. Idaho, Moscow. 83 pp. (OR)

The objectives were to determine the carrying capacity, allowable amounts of sediment and methods to measure levels of fine sediments of 0.25 inches or finer in mountain streams in the Idaho batholith. The sources and the effects of the sand size sediments once they leave the mountain batholith streams are not considered.

Sediment discharge during the high water event of 1973, a year of minimal peak discharge, was insignificant. Project transport rates using the Meyer-Peter, Muller formula, which shows good agreement with empirical data for batholith streams, are presented. The allowable amount of fine sediments to enter these streams was determined by a sediment budget within limits established by the aquatic managers. A method of visually classifying the streambed, uses by aquatic entomologists, correlated well with core samples for determining streambed composition.

Nelson, L. M. 1973. Sediment transport by streams in the Upper Columbia River Basin, Washington. May 1969-June 1971. Prepared Water Res. Div., Wash. District. 87 pp. (OR)

A reconnaissance of sediment transport by streams in the upper Columbia River basin of eastern Washington disclosed that (1) in the mountainous areas snowmelt transports most of the sediment during April-June; and (2) in the lower, semiarid parts of the basin most of the sediment is transported when warm rain falls on extensive accumulations of snow. During the 1970 and 1971 water years the measured suspended-sediment concentrations ranged from less than 1 milligram per liter in many streams to more than 200,000 milligrams per liter in Providence Coulee. The estimated long-term annual suspended-sediment yields range from less than 10 tons per square mile in many basins to more than 500 tons per square mile in Providence Coulee. Man's activities have caused only a slight increase in the magnitude of sediment discharge to the Columbia River. Although cultivation has initiated a large increase in erosion on the Columbia Plateau, the sediment transport by streams has not increased greatly, because there is little surface runoff on the plateau to transport soils to streams.

Neumann, D. A., J. M. O'Conner, J. A. Sherk, and K. V. Wood. 1975. Respiratory and hematological responses of oyster toadfish (*Opsanus tau*) to suspended solids. Trans. Am. Fish. Soc. 104(4):775-781. (OR)

Respiration rates of *Opsanus tau* in suspensions of fuller's earth (2.20 g/liter) and in resuspended Patuxent River sediment (1.58 g/liter) did not differ significantly from rates of fish in filtered water. Oxygen consumption rates of fish exposed to Patuxent River sediments (3.36 g/liter) after 72 h exposure to 11.09 g/liter of the same material exhibited significantly greater ($P<0.05$) variance than control fish. Respiration rates of fish tested in filtered water after 72 h exposure to 10.37 g/liter of Patuxent River sediment were not different from those of control fish. Respiration variances differed between males and females only in Patuxent River sediment suspensions. Fish held in Patuxent River sediment suspensions of 14.6 g/liter for 72 h exhibited no significant changes in erythrocyte count, hemoglobin concentration, micromematocrit, or blood osmolal concentration compared with control fish. Toadfish appear to be largely unaffected by highly turbid conditions.

Noble, E. L., and L. J. Lundeen. 1971. Analysis of rehabilitation treatment alternatives for sediment control. Pages 86-96 *in* J. Morris, ed. Proc. of a Symposium on Forest Land Uses and Stream Environment. (GS)

The aquatic environment of the South Fork Salmon River has been severely damaged in recent years by excessive rates of sediment production. A special study was conducted to determine the source and extent of the damage, and measures required to reduce future sediment production to a "tolerable" level. Linear programming was used as an aid to select from 190 possible treatment alternatives and minimize treatment costs at various levels of sediment reduction. The desired level of sediment could be reached at a cost of $5 million. Debris basins to trap sediment moving in the channel proved to be the most effective and economical type of treatment while control of sediment production for roads and timber harvest on steep, fragile lands would have a very high cost.

Novak, P., and C. Nalluri. 1975. Sediment transport in smooth bed channels. ASCE, J. Hydraul. Div. 101(HY9):1139-1154. (OR)

The problems of incipient motion of sediments forming a loose boundary in sediment transport in open channel flow have been extensively examined by many investigators. The solid transport studies in pipes have been primarily studied with suspended load moving at high velocities of flow and with the description of "critical" velocities corresponding to the incipient deposition. Less attention has been paid to the movement of sediments in pipes as bedload, i.e., in contact with the bed. In open channel flow very little is known about the sediment motion and transport over fixed smooth boundaries. This paper attempts to analyze and summarize incipient motion and sediment transport as bed load in circular conduits and rectangular flumes with smooth beds and free surface flow. The results and conclusions are directly applicable in engineering design. The presented research results form part of the study sponsored by the Science Research Council into turbulence and sediment transport in smooth open channels of circular cross section.

Nuttall, P. M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall. Freshwater Biol. 2:181-186. (OR)

Erosion from a tributary of the River Camel deposited an estimated 10,000 m$^3$ of sand in the main river over a period of two years. The poor incidence of plants and macroinvertebrates from the river was associated with the unstable shifting nature of the sand deposits, rather than turbidity or abrasion caused by particles in suspension. Sand deposition accounted for the low diversity of invertebrate species below the tributary, and resulted in the elimination of several species which were frequent upstream. *Baetis rhodani, Rhithrogena semicolorato*, and Tubificidae were abundant where sand deposition had occurred.

Nuttall, P. M., and G. H. Bielby. 1973. The effect of china-clay wastes on stream investebrates. Environmental Poll. 5:77-86. (OR)

A survey of the macroinvertebrate fauna of rivers receiving china-clay wastes was carried out during 1971-72. Rivers polluted by clay waste supported a sparse population of few species. Rooted vegetation was absent, although clean headstreams and unpolluted reaches supported a rich community of aquatic plants. Control streams supported 36 times the density of animals found at clay-polluted stations. The composition of species was greater in unpolluted rivers, moorland headstreams and at stations downstream of sewage outfalls compared with clay-polluted reaches. *Baetis rhodanii; Perlodes microcephala* and the burrowing forms Tubificidae, Naididae and Chironomidae were in greater abundance in clay-polluted reaches. China-clay pollution either eliminated or reduced the abundance of several species frequent in control streams. The poor incidence of plants and macroinvertebrates from rivers receiving china-clay waste was associated with the deposition of fine inert solids derived from the clay extraction process rather than turbidity or abrasion caused by particles in suspension.

O'Connor, J. M., and J. A. Sherk. 1975. The response of some estuarine organisms to suspended solids. Pages 215-234 *in* J. B. Herbich, ed. Proc. of the Seventh Dredging Seminar. Sea Grant Publ. TAMU-SG-105, September, 1975. (WP)

The effects of suspended particles on primary productivity were determined using the $^{14}$C method; the effect of particles on the filtration rates of zooplankton was determined by feeding $^{14}$C phytoplankton. Effects on fish were estimated by acute and chronic bioassay experiments. Carbon assimilation in phytoplankton, tested in relation to a gradient of concentrations of sand of 0.2-2.0 g/l, decreased in proportion to the concentration. Photosynthesis reduction was mainly a function of light extinction. Filtration of the alga *Monochrysis lutheri* by *Acartia tonsa* decreased and remained low in 500 mg/l of natural silt, while *Eurytemora affinis* showed an initial decrease, followed by an increase which after 3 hr was equal to control. These results are related to the ecology of the organisms. The LD$_{50}$ values of suspended solids for fish ranged from 2.5 g/l for juvenile menhaden to >300 g/l for mummichog. Tolerant species had habitat preferences toward the mud-water interface.

O'Connor, J. M., and J. A. Sherk. 1976. Effects of sedimentation on coastal zone organisms. Pages 6-1 to 6-16 *in* Proc. Third Fed. Inter-Agency Sedimentation Conf. March 22-25, 1976, Denver, Colo. (NTIS)

Some direct and indirect effects of sedimentation on coastal zone organisms are identified and discussed with respect to future increases in expolitation of coastal zone mineral resources (sand and gravel mining, oil and gas extraction), construction, dumping (sewage sludge, dredged material, demolition debris), and dredging. The potential biological effects of particulate organic and inorganic material which has been suspended, resuspended and deposited in the coastal zone will depend at least upon; 1) concentration; 2) composition (mineral types, particle sizes and shapes; 3) sorbed minerals, toxins, or other associated substances; and 4) tolerances of the organisms. Tolerance limits (sensitivities) of organisms to sedimentation can differ with respect to trophic level, life stage, feeding mechanisms, habitat preference (mid-water interface, shoal water, open water) and duration of exposure. At coastal zone sites selected for sedimentation changes, an appropriate basis for preproject decision making could be provided by identification of the most sensitive biological components (important species and life stages) and an adequate knowledge of local conditions.

Olsen, S. 1965. Salmon stream monitoring in the Alaska Region. USDA For. Serv., Juneau, Alaska. 7 pp. (OR)

Because of possible effects of land use on salmon spawning environment in Alaska, a monitoring technique has been developed by the Forest Service in cooperation with the Alaska Department of Fish and Game. The general objective of the monitoring system is to detect changes in the spawning environment that may adversely affect salmon production. Characteristics being monitored in one stream (soon to be followed by two others) are as follows:

1. Composition of streambed spawning areas.

2. Streamflow and water temperature.

3. Stream channel configuration and amount and kind of debris in stream channel.

4. Soil types in the watershed.

5. Production of salmon fry.

6. Adult salmon escapement.

If changes in the salmon spawning environment, thought to be harmful, do occur, remedial measures can be undertaken. On the other hand, practices which may enhance the habitat can be expanded.

Orcutt, D. R., B. R. Pulliam, and A. Arp. 1968. Characteristics of steelhead trout redds in Idaho streams. Trans. Am. Fish. Soc. 97(1):42-45. (OR)

Steelhead spawning behavior and redd construction were studied in 1958 and 1959 in the Clearwater and Salmon River watersheds in Idaho. Steelhead began spawning in early April; spawning peaked between April 20 and May 10 at water temperatures of 36 to 47 F., and was over by June 15. Minimum water depth over a redd was 0.7 feet; maximum water depth exceeded 5 feet. Water velocity 0.4 feet above streambed averaged 2.3 to 2.5 ft/sec. Steelhead favored spawning gravels 0.5 to 4.0 inches in diameter; however, they readily accepted areas with smaller and somewhat larger gravels if 6-inch stones were not abundant. Steelhead tolerated crowding without antagonism; pairs spawned within 4 feet of one another. The average redd occupied 6.5 square yards of gravel, and ranged from 2.9 to 13.4 square yards.

Packer, P. E. 1967. Criteria for designing and locating logging roads to control sediment. For. Sci. 13(1):1-18. (OR)

A recently completed study developed criteria for the design, location, and construction of logging roads in the northern Rocky Mountains to prevent damage to the water resource and to conserve soil. Results reveal which characteristics of watersheds and of secondary logging roads influence erosion of road surfaces and movement of sediment downslope from roads. They define the manner and degree in which these characteristics affect road-surface erosion and sediment movement, and they indicate which characteristics are controllable or alterable by design, management, or choice. They also provide the quantitative criteria needed to develop road design and location requirements that should be considered in planning and executing timber harvest operations, so that soil and water resources will be protected.

Patrick, R. 1973. Use of algae, especially diatoms in the assessment of water quality. Pages 76-95 *in* Biological methods for the assessment of water quality, ASTM STP 528. Am. Soc. Testing Mat. (OR)

Two main systems of approach used to determine if algae can reliably indicate water quality are discussed in this paper. One approach is to observe and analyze natural communities. The effect of a pollutant can be estimated by shifts in species composition and structure of the community in this type of study. The second approach studies a single or a few species in cultures in the laboratory under known and carefully regulated conditions. These studies are valuable in determining the physiological and morphological changes in function rates and polymorphism due to concentration of a given chemical or physical factor.

Pautzke, C. F. 1937. Studies on the effect of coal washings on steelhead and cutthroat trout. Trans. Am. Fish. Soc. 67:232-233. (M)

Young steelhead and cutthroat trout were held in an area of the Cedar polluted with wastes from coal mining operations. Mortalities occured in 1-1/2 to 2-1/2 hours. Dead fish showed extended heart and liver, pale gills, and heavy mucous secretions. It was concluded that coal washings were deleterious to fish.

Pennak, R. W., and E. D. Van Gerpen. 1947. Bottom fauna production and physical nature of the substrate in a Northern Colorado trout stream. Ecology 28(1):42-48. (OR)

The investigation here reported was undertaken primarily to find out whether this principle applies to a typical, unpolluted, northern Colorado trout stream. In addition, it was desired to establish the general qualitative and quantitative composition of the bottom fauna, as compared with stream faunas in other parts of the United States.

Peters, J. C. 1962. The effects of stream sedimentation on trout embryo survival. Pages 275-279 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biological Problems in Water Pollution. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

Five sampling stations were established in Bluewater Creek to measure sediment concentrations and discharge. In the vicinity of the sediment-discharge stations, man-made redds were constructed with sorted gravel, and eyed rainbow trout eggs in hatching boxes were introduced into the redds. Periodically, the Mark VI standpipe apparatus was used to measure intragravel dissolved oxygen and intragravel apparent velocity within the redds. The sampling stations with low sedimentation rates responded with high intragravel dissolved oxygen rates, high intragravel seepage rates (apparent velocities), and low trout embryo mortality. Conversely, the sampling stations with high sediment rates responded with low intragravel dissolved oxygen rates, low intragravel seepage rates (apparent velocities), and high trout embryo mortality.

Phillips, R. W. 1963. Effect of logging on aquatic resources. Ore. State Game Comm., Res. Div. Rep. Pp 105-122. (GS)

The study conducted in the Alsea watershed was primarily concerned with measuring the effect of logging on the production and yield of silver salmon and steelhead. The aim of the investigation was to determine: (1) The effect of a gravel environment on survival; and (2) the effect of logging on the environment. This preliminary report covers the effect of the environment on survival and includes a discussion of: (1) dissolved oxygen and apparent velocity versus emergence; (2) dissolved oxygen versus emergence; (3) gravel size versus emergence; (4) dissolved oxygen content of intragravel water; and (5) gravel permeability.

Phillips, R. W. 1964. The influence of gravel size on survival to emergence of coho salmon and steelhead trout. *In* Proc. of the Fifteenth Northwest Fish Culture Conference. Ore. State Univ., Corvallis, Oregon. (OR)

Experiments testing four sizes of gravel (1/4 to 1/2 inch, 1/2 to 3/4 inch, 3/4 to 1 inch and 1 to 1 1/4 inches) in troughs demonstrated the importance of gravel size in the survival to emergence of coho and steelhead. Emergence was restricted at gravel sizes smaller than 1/2 to 3/4 inch for steelhead and at sizes smaller than 3/4 to 1 inch for coho. Gravel size influenced the weight of steelhead. Only the smaller individuals emerged in 1/4 to 1/2 inch gravel. A similar pattern did not exist for coho, because the gravel sizes tested either prevented emergence entirely or permitted relatively high survival. None were intermediate. Time of emergence was not influenced by gravel size. Pilot experiments on *Cottus perlexus* migration into the gravel indicate that the minimum size adequate for emergence (1/2 to 3/4 inch for steelhead and 3/4 to 1 inch for coho) should be used in spawning channels and incubation boxes where cottid predation is a factor.

Phillips, R. W. 1971. Effects of sediment on the gravel environment and fish production. Pages 64-74 *in* J. Morris, ed. Proc. of a Symposium--Forest Land Uses and Stream Environment. Ore. State Univ., Corvallis. (OR)

Research in the field is summarized. Sediment influences fish in several ways. In suspension: (1) It blocks the transmission of light, reducing algae production; and (2) it damages the gill membranes, causing death where concentrations are high and exposure is prolonged. When sediment settles on the gravel beds, it is harmful in the following ways: (1) It fills the interstices reducing interchange between surface waters and waters within the gravel bed. This reduces the supply of dissolved oxygen to the egg, and interferes with the removal of metabolites (carbon dioxide and ammonia). (2) Sediment also forms a barrier to fry emergence by blocking the route of egress; (3) low dissolved oxygen and the physical barrier effect of sediment appear to be additive in reducing survival; (4) survival after fry emergence is impaired because of a loss of escape cover and a reduction of aquatic organisms that are food for fish. Examples are cited showing that pink and chum salmon survival is inversely related to the amount of sediment in gravel beds.

Phillips, R. W., and H. J. Campbell. 1962. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. 14th Annu. Rep. Pac. Marine Fish. Comm. Year 1961. Portland, Ore. Pp. 60-73. (GS)

The results of two studies designed to determine the effect of three environmental factors on embryonic survival of steelhead trout and coho salmon are reported. The three environmental factors considered are: (1) Dissolved oxygen concentration of the intragravel water; (2) seepage rate of intragravel water; and (3) permeability of the gravel. Also included in the report is a literature review of the effect of dissolved oxygen on embryonic survival.

Phillips, R. W., H. J. Campbell, W. L. Hug, and E. W. Claire. 1966. A study of the effect of logging on aquatic resources 1960-1966. Ore. State Game Comm., Res. Div. Prog. Memo. Fish. Ore. State Univ., Corvallis. 28 pp. (GS)

The scope, methods, and techniques of a logging study are outlined; and some of the initial effects and specific problem areas encountered are presented.

Phillips, R. W., R. L. Lantz, E. W. Claire, and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish. Soc. 104(3):461-466. (OR)

Eight mixtures of sand and gravel were tested in experimental troughs, to simulate hatching conditions in coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*) redds. Fry were released into perforated, open-ended chambers below the gravel surface. An inverse relationship was found between the quantity of fines and emergent survival. Mean emergent survival for coho salmon ranged from 96 percent in the control mixture to 8 percent in 70 percent sand (less than 3.3 mm diameter). Mean emergent survival for steelhead ranged from 94 percent to 18 percent, respectively. Premature emergence of coho fry was related to higher concentrations of fines. These premature fry were smaller, and retained more yolk than fry emerging at normal times.

Phinney, H. K. 1959. Turbidity, sedimentation and photosynthesis. Pages 4-12 *in* E. F. Eldridge and J. N. Wilson, eds. Proc. of the Fifth Symposium--Pacific Northwest on Siltation--Its Sources and Effects on the Aquatic Environment. Portland, Ore. (OR)

The author stresses that "in relating physical and biological facts concerning populations existing in turbid media, certain critical factors must be considered.

1. What is the metabolic status of the population (the $CO_2$/02 ratio). And this does not mean simply B.O.D.'s.

2. What are the light transmitting qualities of the medium?

a. Absorption.

b. Diffuse scattering.

This cannot be simply transmission data nor can it be developed from photometer readings in the field.

3. What are the characteristics of the suspensoids, and the color that is controlling light transmission?

If turbidity and sedimentation are adjudged as prime factors in controlling biological development in a problem situation, nothing less than an all out analysis will prove a waste of time, money and effort in answering the all-important question of why?"

Pickering, R. J. 1976. Measurement of "turbidity" and related characteristics of natural waters. U.S. Geol. Survey, Open-File Rep. 76-153. 5+ pp. (OR)

Attempts to quantify turbidity have led to a proliferation of definitions, methods of measurement, instruments, standards, and units of measure. Turbidity data for natural waters are applied to several uses, including: (1) Determination of the depth to which photosynthesis can occur; (2) aesthetic evaluation of water used for recreation; and (3) estimation of concentration of suspended sediment. Lack of standardization of the measurement often has resulted unwittingly in correlations between unrelated numbers. There is a strong feeling within the hydrologic profession that more precise and definitive sets of methods and terminology are required. Turbidity generally is measured as an optical phenomenon and should be reported in optical units.

The U.S. Geological Survey has adopted the following principles: (1) Standard instruments and methods should be adopted to measure and report the light transmitting characteristics of natural waters in optical units, thus avoiding the use of "turbidity" as a quantitative measure; (2) reporting of "turbidity" in Jackson Turbidity Units, Hellige Units, severity, or Nephelometric Turbidity Units should be phased out; (3) the basis for estimations of sediment concentrations using light measurements should be documented adequately; and (4) the use of transparency measurements by Secchi disk is considered to be acceptable, although light transmittance may prove to be a more precise means of obtaining the same information.

The Geological Survey has established a schedule for implementing the new methods. The schedule calls for application to begin on October 1, 1976, with the transition to be completed at all stations by October 1, 1977. Provisions are made to meet the needs of cooperators who are required by law to collect "turbidity" data.

Platts, W. S. 1970. The effects of logging and road construction on the aquatic habitat of the South Fork Salmon River, Idaho. (Abstract) USDA For. Serv., Zone Fish. Biol.. 4 pp. (GS)

The harvest and resulting road construction of 325 million board feet of timber removed from seven percent of the South Fork Salmon River caused aquatic habitat degradation. To determine the aquatic habitat conditions, data were collected from 325 randomly located stream transects, 670 streambank points, 90 additional stream transects in spawning areas, 155 streambed core samples, and 80 additional streambed core samples in major spawning areas. Results showed the South Fork Salmon River to be a heavily sedimented stream, especially in the salmonid spawning areas. The studies showed that both streambed surface and depth sediment content were very high. The salmon redds contained slightly less fine materials than the overall spawning areas but were not capable of eliminating required amounts of sediment from egg incubation areas which would result in good permeability.

A debris basin was effective in improving the aquatic habitat in the stream immediately below the basin during low and normal waterflows, but it was detrimental to downstream habitat during its initial construction and early existence.

Platts, W. S., and W. F. Megahan. 1975. Time trends in river bed sediment composition in salmon and steelhead spawning areas South Fork Salmon River, Idaho. Pages 229-239 *in* D. Sabol, ed. Trans. 40th N. Am. Wildl. Natur. Res. Conf. (OR)

Riverbed surface conditions deleterious to fish spawning may result if soil disturbances from logging and road construction are allowed to progress without restriction on steep mountain lands in the Idaho batholith. The percentage of fines in the four individual spawning areas studied ranges from 45 to over 80 percent in 1966. Presently, the size compositon of bottom materials is at or near optimum levels in the individual spawning areas, where fines range from 12 to 26 percent; these values should decrease even further in the future. These results show that streams similar to the South Fork Salmon River can recover in time if sediment flows into the stream resulting from acclerated erosion on watershed lands are reduced to levels below the capacity of the stream to flush fines from the system.

The South Fork Salmon River experience demonstrates that land uses in sensitive areas must be carefully planned over both time and space to avoid overloading the system to the point that sediment supplies exceed sediment transport capacities. Only by using a system of programmed land uses is it possible to avoid degradation of the aquatic environment such as occurred in the South Fork Salmon River.

Rana, S. A., D. B. Simons, and K. M. Mahmood. 1973. Analysis of sediment sorting in alluvial channels. ASCE, J. Hydraul. Div. 99(HY11):1967-1980. (OR)

A mathematical model has been presented for predicting the progressive sorting of bed material in straight prismatic alluvial channels with constant discharge and width. This model shows that:

1. If the energy gradient decreases exponentially, the bed material size also decreases exponentially.

2. The sorting coefficient, $a$, along the channel is not constant over long reaches but decreases as the regime of flow changes from lower to upper.

3. The sorting coefficient, $a$, for a given slope function varies with $q$ and C. However, for a given total bed material load, the variation of $a$ is similar for various $q$ - C combinations.

4. In alluvial channels, formed by aggradation of bed material transported from upstream, the channel flow can be in equilibrium considering the quantity of bed material transport. However, in the absence of abrasion, the bed material will be coarsening with time. Thus, strict equilibrium in alluvial channels with nonzero $a$ values, is not possible in the absence of significant abrasion which in sand bed channels is very unlikely.

Reed, R. D., and S. T. Elliott. Effects of logging on Dolly Varden. Alaska Dep. Fish Game, Fed. Aid in Fish Restoration, Div. Sport Fish. Annu. Prog. Rep., Proj. F-9-4, Job R-IV-B. Juneau, Alaska 62 pp. (OR)

This report presents the results of the second year of study on the effects of logging on Dolly Varden, *Salvelinus malma*. Study emphasis included general surveys of logged streams throughout southeast Alaska; aquatic insect surveys; monitoring prelogging fish populations of eight streams within the Hood Bay watershed; and compiling an annotated bibliography on effects of logging on fish.

Twenty-two logged watersheds located throughout southeast Alaska were surveyed. Familiarization and photographic documentation of the most common logging damage to streams was obtained.

During the surveys, aquatic insect populations were sampled to obtain species composition and distribution of the more common species.

Comparisons were made bwtween logged and unlogged areas, which revealed a decrease in species diversity within the altered stream sections.

Stream monitoring with baited minnow traps on eight selected streams in the Hood Bay watershed was continued. Monthly catch per trap analysis results revealed no significant trends in population sizes, nor did the comparison of this year's results with those of last year.

An annotated bibliography on the effects of logging on fish, containing over 90 citations, was compiled.

Rees, W. H. 1959. Effects of stream dredging on young silver salmon (*Oncorhynchus kisutch*) and bottom fauna. Wash. Dep. Fish., Res. Pap. 9(2):52-65. (OR)

A program was begun in July, 1952, and terminated in August, 1953, to measure the effects of dredging and stream channeling on fish and bottom organisms in Little Bear Creek, a small stream populated by silver salmon and a tributary to the Sammamish River 15 miles northeast of Seattle.

Random bottom samples were taken periodically in test and control areas to measure population changes in food organisms. Dredging in September, 1952, eliminated 97 percent of the bottom organisms in the test area. The dredged area showed a reduced fauna population for five months and then began to recover in February, 1953. By July, 1953, it had recovered completely.

A predominance of dipterous larvae over the other bottom organisms was found in the stomach contents of young silver salmon, even during periods of low dipterous production.

Population estimates of zero-group silver salmon and trout fingerlings showed a decrease of 69 percent and 81 percent respectively immediately after dredging in September, 1952. Fish were killed by the drag line or by being trapped in the various isolated sections of the old channel. Changing of the streambed also caused indirect effects such as destruction of the food supply and the elimination of suitable living area. Population estimates made a year later (August, 1953) compared favorably in test and control areas with estimates made during August, 1952.

The relationship of waterflow (velocity) and bottom type to organism type indicated that Diptera predominate in slow, sandy bottom areas. Coleoptera preferred moderate velocity with sand and gravel, and Ephemeroptera, Plecoptera, and Trichoptera all preferred swift flow and gravel bottom.

Reis, P. A. 1969. Effects of inorganic limestone sediment and suspension on the eggs and fry of *Brachydanio rerio*. M.A. Thesis. Depauw Univ., Greencastle, Indiana. 58 pp. (OR)

Water quality standards are often generalized and incomplete due to the many types of pollutants and their various lethal concentrations. This research was conducted to determine if inorganic limestone sediment and suspension should be regarded as important water pollutants;

and if so which concentrations are likely to be critical for the early development of fish. The eggs and fry of thw warm-water Cyprinid *Brachydanio rerio* were subjected to various concentrations of finely-divided limestone particles (less than 0.074 mm).

One series of trials subjected eggs to various sediment depths. Experimental eggs suffered no unusual number of mortalities and hatched in the same period of time, or earlier, than control eggs. When eggs were incubated in various limestone suspensions a general trend of earlier median hatching times again resulted. Eggs incubated in suspensions for 32 hours, then transferred to clear water also exhibited short median hatching times. Limestone suspensions were also deleterious to successful fry development.

Renard, K. G. 1976. A time related automatic total-load sediment sampler. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. PP. 7-17 to 7-29. (OR)

A total-load, automatic, sediment sampler was developed and tested for use with small runoff measuring flumes. The system collects individual, total-load, sediment samples which provide periodic sediment concentration data during a runoff event. The system consists of two parts, the sampler and the collector. The sampler is a vertical slot that traverses on a horizontal rail through the flow at the flume's exit. The traverse speed is regulated by flow depth and aliquot size. The collector is a revolving table with a capacity of 18 two-liter ≈ 0.5 gal.) bottles. Table rotation is regulated by a timer and a new bottle is filled with each traverse. The time of each traverse is recorded on the stage record. The system is powered by a 12-volt, DC battery charged by a solar generator, which allows using the system in remote areas where conventional electrical power is not available.

Rendon-Herrero, O. 1974. Estimation of washload produced on certain small watersheds. ASCE, J. Hydraul. Div. 100(HY7):835-848. (OR)

The need for quantitative evaluation of washload is of paramount importance at the present time, since sediment is considered to be a pollutant. Washload can have deleterious effects as a sediment-volume encroachment in streams and other bodies of water.

A method is presented in this paper which is applicable to certain small watersheds and which can enable the estimation of sediment discharge on a storm basis depending on the amount of effective precipitation.

Resler, R. A. Guides for protecting water quality. USDA For. Serv. PNW. (EPA)

The guides are intended to reflect some of the factors that should be considered in evaluating the susceptibility of streams to changes in water quality. When this evaluation is made, the land manager can better prescribe practices which will best meet management objectives.

The guidelines are to familiarize the user with some of the factors and influences that should be considered in making an on-the-ground decision on a case-by-case basis and to provide a means for predicting temperature changes.

Rice, R., R. Thomas, and G. Brown. 1975. Sampling water quality to determine the impact of land use on small streams. ASCE Watershed Mgmt. Symposium, Utah State Univ., Logan, Utah. (OR)

By habit, we are used to dealing with sediment in terms of erosion, and expressing it in annual values-tons per square mile per year. With water quality standards, the emphasis shifts to evaluation of individual samples. And this is an extremely difficult statistical problem. The usual procedure is to use time series for such analyses with data points at regular intervals of time or continuous records sampled at regular intervals. We did not have that option with our data.

The analyses of serially correlated data with irregular sampling intervals has not yet been worked out to our knowledge.

Our revised objective is to describe for you the variation observed in water quality in small streams in the Pacific Northwest using sediment as an example. We also wish to discuss the statistical implication of this variation and provide an example of the difficulties this presents in monitoring and regulating non-point source pollution in small streams.

What conclusions can we draw from this analysis and our understanding of current water quality standards? First it means that current standards, derived for controlling pollution on large river systems, are inapproapriate for small streams. Standards must be rewritten to include a complete specification of performance characteristics. Second, it means that the development of the standard and the monitoring scheme for judging compliance must be done concurrently. Third, we need to develop statistical and analytical models which are able to cope with the variation and the serious problems posed by serial correlation of sediment samples.

Ringler, N. H., and J. D. Hall. 1975. Effects of logging on water temperature and dissolved oxygen in spawning beds. Trans. Am. Fish. Soc. 104(1):111-121. (BA)

The temperature and dissolved $O_2$ content of intragravel water were measured in three Oregon [USA] coastal streams between June 1968-June 1969. In 1966, the watershed of one stream was completely clearcut, and that of a second stream partially clearcut in staggered settings. A third watershed was left unlogged. Clearcut logging resulted in increased temperature of intragravel water in salmon and trout spawning beds and decreased concentrations of dissolved $O_2$. The changes were related largely to reduced forest cover over the stream surface and to deposition of fine sediment in the gravel. No serious reduction in survival to emergence of coho salmon occurred along with the observed changes in temperature or dissolved $O_2$. A decrease in the resident population of cutthroat trout after logging may have been related to these changes.

Roback, S. S. 1962. Environmental requirements of Trichoptera. Pages 118-126 *in* C. M. Tarzwell, ed. Trans. Third Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

Over many years, the Limnology Department of the Academy of Natural Sciences of Philadelphia has conducted stream surveys at over 100 stations in the United States and Canada. At any of these stations, the caddisfly larvae form about 10 percent of the total insect fauna. The ranges of occurrence for each of 14 chemical factors are given for the dominant genera, and in some cases families (where there were too few records) of caddisfly larvae. Too few of the larvae collected can be placed as to species with sufficient certainty to make data at the species level meaningful. Laboratory experiments on the toxicity of various chemicals to caddisfly larvae are practically nonexistent; however, the results of one set of experiment performed at the Academy are presented.

Rosgen, D. L. 1976. The use of color infrared photography for the determination of suspended sediment concentrations and source areas. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-26, 1976. Pp. 7-30 to 7-42. (OR)

The concepts and special techniques for applying color infrared photography in sediment studies are presented. These techniques were developed and evaluated through a low elevation color infrared photography flight and concurrent water quality sampling conducted on 164 km (100 miles) of stream over the West Fork of the Madison River in southwestern Montana. The concentrations and sources of sediment produced during peak snowmelt runoff were determined by photo densitometric analysis coupled with specifically located ground control stations.

Excellent correlations were established by regression analysis of the ground truth variables including stream width to discharge and suspended sediment to turbidity. Photo density was correlated with suspended sediment and turbidity, both produced strong correlations which were significant at the 99 percent confidence level. These correlations made it possible to determine reliable estimates of sediment concentrations from the aerial photography where stream measurements were not obtained.

Sediment production estimates were made by using the concentration data linked with stream discharge as a function of stream width. The photoscale control markers were used to obtain stream widths from the aerial photography.

The photographic analysis indicated that the majority of the suspended sediment sources during the snowmelt runoff event were derived primarily from channel erosion. Additional intrepretations which can be derived from photo analysis are also presented and discussed.

Royce, W. F. 1959. On the possibilities of improving salmon spawning areas. Trans. 24th N. Amer. Wildl. Conf., Wildl. Mgmt. Inst. Pp. 356-366.

Factors affecting the variability of salmon return numbers, and more specifically, the high mortality of intragravel life stages, were discussed. Emphasis was placed on the need for maintaining adequate waterflow and dissolved oxygen levels in spawning redds. Research needs mentioned included the need for more information on intragravel ecology and the physical stream variables and their effects.

Ruggles, C. P. 1966. Depth and velocity as a factor in stream rearing and production of juvenile coho salmon. Can. Fish. Cult. 38:37-53. (OR)

Coho salmon smolt production was measured in four artificial stream channels 200 feet long by 20 feet wide. Two years' data are presented on the effect of depth and velocity on fish food production, smolt production and fish behavior. A known number of wild coho fry were introduced to each channel and allowed to take up residence in the channel on a volitional basis.

The amount of downstream migration was influenced by the availability of low velocity water. Over twice as many fry remained in a pool-like environment as in a riffle-like condition; an intermediate number remained when the depth-velocity situation was somewhere between pool and riffle. Whereas fish preferred the pool-like environment, fish food production was much higher in the riffle-like environment. The most coho smolt production occurred in a channel composed of one-half riffle and one-half pool. Differences in behavior were noted between coho fry which had migrated upstream of their place of emergence and fry which had moved downstream from their place of emergence.

Ryan, P. 1970. Design and operation of an in situ frozen core gravel sampler. Tech. Rep. 1970 - 12. Can. Dept. Fish. For., Fish Serv., Pac. Reg. (OR)

The objective of the gravel sampler design is to provide a method of extracting a near undisturbed sample of gravel and silt from shallow salmon spawning streams. The sample is frozen in situ using "dry ice" dissolved in acetone as a freezing mixture.

Samsel, G. L. 1973. Effects of sedimentation on the algal flora of a small recreational impoundment. Water Res. Bull. 9(6):1145-1152. (OR)

Investigations were initiated to evaluate the effects of sedimentation on the algal composition, primary productivity rates and chemical nutrient concentrations of a 17-acre recreational impoundment in central Virginia. Comparisons during the winter seasons of 1972-1973 indicated that as a result of sedimentation, from lake front home construction, the total numbers of algal genera in the lake decreased from 24 to 16, productivity as measured by $^{14}CO_2$ and total extractable chlorophyll decreased two-fold, and several important nutrients, i.e., $NH_4$+N, $SiC_2$ and $PO_4$-P increased significantly.

Saunders, J. W., and M. W. Smith. 1965. Changes in a stream population of trout associated with increased silt. J. Fish. Res. Board Can. 22(2):395-404. (OR)

Low standing crops of brook trout, *Salvelinus fontinalis*, were closely associated with silting in Ellerslie Brock, Prince Edward Island, and appeared to result from the destruction of hiding places. Spawning was also curtailed by silting. Following scouring, trout stocks soon increased. The remarkable adaptability of trout to silting, in a habitat with favorable flow and water temperature, was illustrated.

Saxton, K. E. 1972. Gaging sediment-laden flows with V-notch weirs. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. Pp. 7-43 to 7-53. (OR)

Watersheds with areas of less than 1 $mi^2$ (2.59 $km^2$) often have streamflow with stages that rise and fall rapidly. These rapid stage changes prevent accurate field calibration of streamflow gaging stations by usual techniques; therefore, a reliable, precalibrated measuring device is necessary. Also, the streamflow from these small watersheds is often heavily laden with sediment (up to 200,000 ppm), and the alluvial stream channels change their cross section and slope upstream of the measuring device. These sloping and aggrading approach chemicals can change the streamgage calibration.

Broad-creasted, V-notch weirs, developed by the U.S. Soil Conservation Service, have been used extensively. Recent evidence has shown that different approach channel slopes and shapes and sediment deposits cause significant deviations from the original calibrations. Model studies were conducted to define the effect of approach channel geometry and sediment deposits on the weir calibrations. A rigid-boundary model was used for the tests. Channel slopes were 0.0, 0.5, 1.0, 1.5, and 2.0 percent for several approach channel cross sections. The results provide improved calibrations for broad-crested, V-notch weirs for gaging sites in alluvial channels.

Schlapfer, T. A. 1972. Title 2100-multiple use management. USDA For. Serv., For. Serv. Mgmt., Reg. 6, Suppl. 11, Code 2121-33, Portland, Ore. Pp. 27-34. (EPA)

The manual provides new policy and guidelines for protecting water quality through establishment of streamside management units (SMU). Stream classification is determined by use made of water and each class has certain water quality objectives and criteria to be met in the conduct of land management activities.

Schroeder, K. B., and C. H. Hembree. 1956. Application of the modified Einstein procedure for computation of total sediment load. Trans. Am. Geophys. Union 37(2):197-212. (OR)

A method that enables good estimates to be made of total sediment load has been tested with data from several western streams. The method, which uses both theoretical and empirical formulas, combines a modification of Einstein's procedure for computing bed-material load and the usually available data from suspended-sediment measurements. Basic data, including data from large natural and artificial turbulent flumes, and the results of computations are given.

Servizi, J. A., R. W. Gordon, and D. W. Martens. 1969. Marine disposal of sediments from Bellingham Harbor as related to sockeye and pink salmon fisheries. Int. Pac. Sal. Fish. Comm., Prog. Rep. 23. 38 pp. (OR)

A recent proposal for dredging and marine disposal of sediment from Whatcom Waterway, Bellingham, was of concern to fisheries agencies since the proposed disposal area was utilized by several fish stocks, including migrating Fraser River sockeye and pink salmon. Laboratory study indicated that two types of sediment were involved. Sediment from the inner harbor consisted primarily of putrefying pulp fibers which exerted a significant oxygen demand, created substantial turbidity, and were toxic to juvenile sockeye salmon because of their hydrogen sulfide content. Hydrogen sulfide was readily dissipated from inner harbor sediment by diffused air but was not removed by exposure for a few hours to the atmosphere. Various methods of widespread dispersal to dilute the sediment appeared impractical, and it was concluded that land disposal of inner harbor sediment would be necessary to protect fish stocks. Sediment from the outer harbor was a natural silt, not containing hydrogen sulfide, but exerted an oxygen demand and created a highly turbid mixture which settled very slowly. Because dumping of this sediment at the proposed site could also prove harmful to fisheries, hydraulic dredging and local disposal adjacent to the outer harbor was recommended.

Shapley, P. S. 1964. Effects of logging on the productivity of pink salmon streams in Alaska. Sal. Studies, Periodic Rep. No. 4, Fish. Res. Inst., Univ. Wash., Seattle. 24 pp. (OR)

The Fisheries Research Institute, under contract to the Bureau of Commercial Fisheries, began a study of the biological aspects of the effects of logging in 1956. The studies have been made in cooperation with the U.S. Forest Service, which has undertaken studies of the physical environment since 1949. Streams that have been studied include Harris River, Indian, Twelvemile, Old Tom, and Maybeso Creeks.

Prior to the study, the environmental factors influencing the growth and development and causing mortality of salmon eggs and larvae were poorly understood. The past research at Hollis, and the resulting publications and manuscripts now in press have provided substantial answers.

The major causes of mortality have been found to be: 1) Superimpositions; 2) freezing; 3) the inadequate supply of good-quality intragravel water; and 4) gravel shift (erosion of and deposition of material on the streambed) caused by floods. Stream environmental changes due to logging have been found to be mainly the result of the addition of logging debris or increased sedimentation. In general, changes due to logging have been difficult to separate from natural fluctuations. The studies have two major objectives: 1) To determine how the quality of spawning bed environment, as it pertains to growth, development and mortality of eggs and larvae, is affected by logging; 2) to provide criteria that can be used to increase production of fry by improved spawning areas or by constructing artifical spawning areas.

Shapley, P. S., and D. M. Bishop. 1965. Sedimentation in a salmon stream. J. Fish. Res. Board Can. 22(4):919-928. (OR)

Sediment was artificially added to a small southeastern Alaskan salmon stream. Observations in sedimented and control riffles indicate that the amount of sediment settling to the stream bottom decreases exponentially with distance downstream. The dissolved oxygen content of intragravel stream water remained high in sedimented riffles. The added sediment was removed from streambed gravels by fall freshets and floods.

Shapovalov, L. 1937. Experiments in hatching steelhead eggs in gravel. Calif. Fish Game 23(3):208-214. (OR)

The purpose of the experiments was to determine at least partially the effectiveness of natural spawning of steelhead trout, *Salmo gairdnerii*, by simulation of natural conditions, and to discover what happens from the time the eggs are deposited in the gravel to their emergence from the gravel as fry.

In each of two experiments eggs from one adult sea-run fish were split into two lots, one of which was placed in gravel and the other in a standard hatching basket as a control.

In nature the percentage of deposited eggs which emerge from the gravel as fry may vary widely. It may be quite low (29.8 percent) under adverse conditions (silting, caused by flood, as here, or mining), and on the other hand quite high (79.9 percent) under good conditions. Some authors believe that under natural conditions poor fertilization occurs, and that but a small percentage of the eggs deposted become fish, but the present writer is inclined to believe, on the basis of field observations and the present experiments, that the percentage of eggs which are fertilized, hatch, and emerge from the gravel is rather high and that the heaviest losses occur during the fry stage.

Shapovalov, L., and W. Berrian. 1940. An experiment in hatcing silver salmon (*Oncorhynchus kisutch*) eggs in gravel. Trans. Am. Fish. Soc. 69:135-140. (OR)

The eggs from five adult sea-run silver salmon (*Oncorhynchus kisutch*) were divided into two lots: 8,239 eggs were buried in gravel in a standard hatchery trough and 7,500 placed in a standard hatching basket as a control. Natural conditions were simulated as closely as possible with the gravel eggs. The eggs required 772.3 temperature units (t.u.) to maximum hatch (control), 1,084.3 t.u. to earliest emergence from the gravel, and 1.155.6 t.u. to maximum emergence from the gravel. Initial to final emergence required at least 38 days. Of the eggs buried, 10.2 percent emerged from the gravel. In the control, 65.9 percent of the eggs hatched and 48.2 percent survived to the time that the experimental fish had finished emerging from the gravel. Examination of the gravel and the dead eggs in it at the conclusion of the experiment and observations made during previous experiments support the view that silt carried by unusually severe floods smothered many of the eggs in the gravel. This fact seems to account in large part for the small percentage of salmon emerging from the gravel. 56 days after initial emergence from the gravel, the experimental fish averaged 23.8 fish per ounce (1.19 grams each, live weight) while the control lot averaged 27.6 fish per ounce (1.13 grams each). During these 56 days only 48 of the experimental fish died, whereas the mortality in the control lot for the same period totaled 905. In the final two weeks, however, the average daily mortality in the control was only one fish.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdnerii gairdnerii*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Calif. Dep. Fish Game, Fish. Bull. No. 98. 375 pp. (GS)

The report describes the life history of the steelhead rainbow trout and the silver salmon. The authors discuss: (1) The correlation between number of eggs and size of fish; (2) the relationship between hatching time and temperature; (3) the effects of silting on the duration of survival; (4) factors influencing growth, timing and size of migration; and (5) the improvement of the biological and physical habitat.

Shaw, P. A., and J. A. Maga. 1942. The effect of mining silt on yield of fry from salmon spawning beds. Calif. Dep. Fish Game 29(1):29-41. (OR)

In view of the extensive mining activity along trout streams and within watersheds that are essential to the maintenance of California salmon and steelhead, an experimental study was conducted to aid in settling the existing controversy and establish a factual basis for adequate but just enforcement action.

Experiments were conducted to determine the yield of fry from salmon eggs in gravel nests subjected to mining silt as compared to the yield from similar nests without silt additions.

From the data presented in this paper it is evident that the yield of fry from eggs hatched in gravel beds supplied with normal hatchery water is far below that attained by the usual procedure of basket hatching in flowing water. The experiments further show that mine silt deposited on gravel spawning beds during either the early or later stages of incubation results in negligible yields of fry and is therefore a serious menace to natural propagation.

It is apparent that adequate control to prevent the discharge of mining silt where spawning grounds may be affected is essential to the preservation of normal fish populations, and legislation to secure the necessary protection is therefore recommended.

Shelton, J. M. 1955. The hatching of chinook salmon eggs under simulated stream conditions. Prog. Fish. Cult. 17(1):20-35. (OR)

From early in November 1952 to early in July 1953, the planting and hatching of chinook salmon eggs in gravel was studied to determine its value as a tool of fishery management in the Columbia River area.

The average hatch for the eggs planted under different sets of variables in the gravel was 96 percent. Comparison of these variables reveals that the difference in percentage hatch is insignificant. (It is considered possible that the mortality caused by crushing of eggs could be reduced and the percentage hatch thus increased proportionately.

The mortality of the planted eggs was divided into two categories: (1) That caused by the crushing of eggs; and (2) that which resulted from unknown causes (primarily percolation).

In the beds of small gravel only 13 percent of all the eggs emerged as fry, but 87 percent emerged in the large gravel beds.

Shelton, J. M., and R. D. Pollock. 1966. Siltation and egg survival in incubation channels. Trans. Am. Fish. Soc. 95(2):183-187. (OR)

Fall chinook salmon eggs in Abernathy incubation channel suffered as much as 85 percent mortality when 15 to 30 percent of the voids in the gravel beds were filled with sediment. With one 70-foot section of the channel used as a silt-settling basin, the mortality was reduced to 10 percent or less. We believe that a siltation control system consisting of a flushable sand trap and settling basin constitute the most economical means of reducing the amount of sediment entering this and similar channels.

Sheridan, W. L. 1962. Waterflow through a salmon spawning riffle in southeastern Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep., Fish. No. 407. 20 pp. (GS)

The following characteristics were studied in a small salmon stream in southeastern Alaska from 1956 to 1959: (1) Dissolved oxygen content of ground water; (2) variation of dissolved oxygen with depth in streambed; (3) temperature of ground water; (4) extent of ground-water seepage; (5) interchange of flowing stream water and water of streambed gravels; and (6) flow of water in the gravel of streambank and gravel bar.

Ground water was generally low in dissolved oxygen content, and dissolved oxygen levels decreased with depth in streambed. Because of these and other points discussed in this paper, I conclude that the main source of intragravel water of high oxygen content is the flowing stream.

Sheridan, W. L. 1968. Land use and sediment. Pages 62-79 *in* R. T. Myren, ed. Logging and Salmon. Proc. Forum, Am. Inst. Fish. Res. Biol., Alaska Dist., Juneau, Alaska. (GS)

Although there is little doubt that logging and road construction contribute some sediment to salmon streams, there is no evidence to show that these activities, when conducted according to protective clauses included in all timber sale contracts, have damaged the salmon resource in southeastern Alaska.

Sheridan, W. L., T. Hoffman, and S. Olson. 1965. A technique for monitoring effects of land use on salmon streams in Alaska. 45th Annu. Conf., West. Assoc. Fish Game Comm., Proc. 1965. Pp. 155-159. (GS)

Because of possible effects on salmon spawning environment in Alaska, a monitoring technique has been developed by the Forest Service in cooperation with the Alaska Department of Fish and Game. The general objective of the monitoring system is to detect changes in the spawning environment that adversely affect salmon production. Characteristics being monitored in one stream (soon to be followed by two others) are as follows:

1. Composition of streambed spawning areas.

2. Streamflow and water temperature.

3. Stream channel configuration and amount and kind of debris in stream channel.

4. Soil types in the watershed.

5. Production of salmon fry.

6. Adult salmon escapement.

If changes in the salmon spawning environment, thought to be harmful, do occur, remedial measures can be undertaken. On the other hand, practices which may enhance the habitat can be expanded.

Sheridan, W. L., and W. J. McNeil. 1960. Effects of logging on the productivity of pink salmon streams in Alaska. Pages 16-17 *in* Ted S. Y. Koo, ed. Res. Fisheries. Coll. Fish. Contrib. 77, Univ. Wash., Seattle. (GS)

The broad plan of the work carried out at Hollis, southeast Alaska, was to define normal patterns before logging so that the changes might be measured as logging progressed. Changes studied were year-to-year escapements of adult spawners, the abundance of downstream migrants, survival rates of eggs and alevins in gravel, distribution and intensity of spawning, and the quality of the environment.

Sheridan, W. L., and W. J. McNeil. 1968. Some effects of logging on two salmon streams in Alaska. J. For. 66(2):128-133. (EPA)

Sedimentation of spawning beds and density of pink salmon were observed before and after logging in two streams in southeastern Alaska. The study lasted seven years (1958-1964). Although the amount of fine particles in spawning beds increased significantly, the amount in 1964 (five years after logging began) was not significantly greater than in 1959. Densities of salmon spawners and fry increased in the sampling areas during the period of this study. The increases were probably due to the abolition in 1969 of salmon traps (formerly the primary means of catching salmon).

Sheridan, W. L., R. W. Wilke, and S. T. Olson. 1968. The gravel cleaner ("riffle sifter"). USDA For. Serv., Prog. Rep., 1967, Alaska Reg., Juneau, Alaska. 8 pp. (OR)

Research in fisheries and engineering has shown that egg to fry survival of salmon embryos is higher in sediment free gravels. For this reason, the Forest Service is developing equipment to remove sediment from spawning gravels. A prototype model was developed by Forest Service engineers in 1964, and a working model was developed by the Clark Equipment Company in 1966. The equipment was tested in Alaska in 1966 and 1967. Although mechanical failures precluded thorough testing in Alaska, it was demonstrated that the equipment would remove large quantities of sediment from streambed gravels and that the principle of jetting the fines to the surface where they can be sucked up and disposed of is sound. The history of development and the results of testing of the "riffle sifter" are given in this progress report. It is not anticipated that a production (working) model will be available for use in Alaska prior to 1969.

Sherk, J. A., Jr. 1971. The effects of suspended and deposited sediments on estuarine organisms, literature summary and research needs. Nat. Res. Inst., Univ. Maryland, Chesapeake Biological Laboratory, Contrib. No. 443, Solomons, Maryland. 73 pp. (M)

An extensive summary and discussion of literature related to the effects of sediment on biological systems, filter-feeding organisms, and offshore waste disposal are presented. Research needs on the effects of suspended and deposited silt are proposed.

In the section of sediment effects on biological organisms the author discusses: Loss of habitat, decrease in euphotic zone depth, oxygen demand, nutrient sorption and release, primary production, community disruption, mortality and other gross effects.

The section involving sediment effects on filter-feeding organisms includes: Pumping and feeding, character of the bottom and larval metamorphosis, and larval and egg development. The problems and biological effects resulting from offshore disposal of particulate wastes are discussed and information from some studies related to these effects is presented.

Research needs in the area of suspended and deposited sediments are fairly extensive. A standardization of study methods and a need for quantitative knowledge of the physical aspects of suspended matter is indicated as well as complete studies incorporating the total interaction of environmental change to the lethal effects on all life stages of the organisms studied. These aspects are important "in order to provide complete predictability of the effects of environmental change."

Sherk, J. A., J. M. O'Conner, D. A. Neuman, R. D. Prince, and K. V. Wood. 1974. Effects of suspended and deposited sediments on estuarine organisms - Phase II. Final Report, September 17, 1970-December 31, 1973. Nat. Res. Inst., Univ. Maryland, College Park, Maryland. 299 pp. (NTIS)

A three-year laboratory study identified biological components of selected populations of estuarine organisms which were most sensitive to the effects of particle size and concentration of: (1) Suspended mineral solids similar in size to sediments likely to be found in, or added to, estuarine systems in concentrations typically found during flooding, dredging, and disposal of dredged material; and (2) natural sediments in identical experiments. Significant mortality of estuarine fishes was demonstrated at these suspended solids concentrations. Estuarine fishes were classified using the results of static bioassays as tolerant (24 hr $LC_{10}>10\ g\ l^{-1}$), sensitive (24 hr $LC_{10}<10>1.0\ g\ l^{-1}$), or highly sensitive (24 hr $LC_{10}<1.0\ g\ l^{-1}$) to fuller's earth suspensions. Generally bottom-dwelling fish species were most tolerant to suspended solids; filter feeders were most sensitive. Early life stages were more sensitive to suspended solids than adults. Bioassays with natural sediments indicated that suspensions of natural muds affect fishes in the same way as fuller's earth, but higher concentrations of natural material were required to produce the same level of response. The effect of finely divided solids on fishes was dependent on several characteristics of suspended particles with different mechanisms operative in producing mortality in fishes, although the cause of death was the same: Anoxia. Sublethal solids effects of fishes were identified: Hematological compensation for reduction in gas exchange across the gill surface, abrasion of the body epithelium, packing of the gut with large quantities of ingested solids, disruption of gill tissue, increased activity, and reduction in stored metabolic reserves. Oxygen consumption of striped bass and white perch swimming at controlled levels of activity was generally reduced during exposure to suspensions of fuller's earth and natural Patuxent River sediments. Carbon assimilation by four species of phytoplankton was significantly reduced by the light attenuating properties of fine silicon dioxide suspensions. Ingestion of radioactive food cells by two species of calanoid copepods was significantly reduced during exposure to suspensions of fuller's earth, fine silicon dioxide, and natural Patuxent River silt. With adequate knowledge of local conditions (life history stages, sediment types, sediment concentrations, seasonal and resident species, duration of exposure, and habitat preference) at estuarine sites selected for environmental modification, our efforts provide baseline data for preproject decision making based upon concentration effects of different types of suspended sediments.

Sherk, J. A., J. M. O'Conner, and D. A. Neumann. 1976. Effects of suspended solids on selected estuarine plankton. Misc. Rep. No. 76-1. Coastal Eng. Res. Cent., Fort Belvoir, Va. 51 pp. (NTIS)

A three-year laboratory study identified biological components of selected populations of estuarine organisms which were most sensitive to the effects of particle size and concentration of: (a) Suspended mineral solids similar in size to sediments likely to be found in, or added to, estuarine systems in concentrations typically found during flooding, dredging, and disposal of dredged material; and (b) natural sediments in identical experiments.

Shumway, D. L., C. E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Am. Fish. Soc. 93:342-356. (OR)

Embryos of coho salmon, *Oncorhynchus kisutch* (Walbaum), and steelhead trout, *Salmo gairdneri gairdneri* (Richardson), were reared from fertilization of the eggs to hatching, at about 10°C, at different concentrations of dissolved oxygen ranging from about 2.5 to 11.5 mg/liter and at different water velocities ranging from about 3 to 750 cm/hour. Some of the embryos rested on porous plates, while others were buried in glass beads so as to simulate natural conditions more closely. Fry from embryos reared at low and intermediate oxygen concentrations hatched later and were smaller in size at hatching than fry from embryos reared at concentrations near the air-saturation level. At all oxygen concentrations tested, reduced water velocities resulted in reduced size of hatching fry. This effect of velocity was nearly as pronounced at high oxygen concentrations as at low concentrations. The effect of the difference of water velocities tested was less than the effect of the difference of oxygen concentrations tested. When some embryos were buried in glass beads while others were not, and the discharge rates of water through cylinders containing the embryos were the same, the fry that hatched in the cylinders containing beads were larger in size than those in cylinders without beads. This effect is ascribed to the increase of water velocities around the embryos buried in beads. It was usually most pronounced when a mixture of large and small beads was used.

Silver, S. J., C. E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Am. Fish. Soc. 92(4):327-343. (OR)

Embryos of steelhead trout, *Salmo gairdneri gairdneri* (Richardson), and chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), were reared from fertilization of the eggs to hatching at different constant oxygen concentrations and water velocities. For this purpose, an apparatus was developed that makes it possible to control oxygen concentration independently of water velocity, which was maintained at levels ranging from 6 to 1,350 centimeters per hour. Measurements of the embryos and hatched fry indicate that water velocities must be high enough not only to transport enough oxygen to the redd for supplying the total requirement of all embryos, but also to deliver sufficient oxygen to the surface of the chorion enveloping the indivual embryo. Steelhead embryos held at 9.5°C and chinook salmon embryos held at 11°C all died at an oxygen concentration of 1.6 mg/l. Survival of large percentages of embryos reared at concentration as low as 2.5 mg/l was apparently made possible by reduction of respiration rates and consequent reduction of growth and development rates. Sac fry from embryos reared at low and intermediate oxygen concentrations were smaller and weaker than sac fry from embryos reared at high concentrations. Although weak sac fry may survive under laboratory conditions, they cannot be expected to do so in nature. The size of steelhead trout and chinook salmon fry at hatching probably was dependent on water velocity even at velocities as high as 740 and 1,350 cm/hr, respectively, and on oxygen concentration even at concentrations near saturation levels. Mean size differences among embryos reared under different conditions at the higher velocity and oxygen-concentration levels were not great, particularly in the case of the steelhead trout.

Silverston, E., and E. M. Laurse. 1976. Patterns of scour and fill in pool-rapid rivers. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. Pp. 5-125 to 5-126. (OR)

Because the change in head on a critical control (rapid or weir) it is less than the change in equilibrium depth in the pool upstream, a pool will eventually scour with an increase in flow and fill with a decrease in flow. However, because the supply of sediment to a pool is dependent on the conditions at the outlet of the pool just upstream, initially there may be either scour or fill in the downstream pool with an increase in flow. Indeed, a pool following several other pools may behave in a seemingly erratic manner because its sediment supply is affected by what happens in each of the upstream pools.

Skinner, J. V., and J. P. Beverage. 1976. Instrumentation-automatic collection of sediment data. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. Pp. 7-1 to 7-16. (OR)

The Federal Inter-Agency Sedimentation Project has included research of methods of automating the collection of suspended-sediment data. Several approaches have been investigated ranging from automatic sample collection to automatic sample analysis. To automate sample collection, several forms of pumping samplers have been developed. To automate sample analysis both direct and indirect methods have been studied. Analysis by indirect methods have included the influence of suspended sediment on conduction of electric currents and on radiation from acoustic, visible light, and gamma sources. Analysis by direct methods have included different techniques for measuring the bulk density of water-sediment-mixtures. Advantages and disadvantages of each approach are summarized, and suggestions for future research and development are offered. Experience indicates that, to facilitate data collection during the near future, one practical system consists of automatic sample collectors that supply samples to semiautomatic laboratory-based analyzers. For the more distant future, it would be desirable to develop a sample collector and sample analyzer combination suitable for continuous field operation.

Development of a sampler-analyzer combination has been hampered for lack of an instrument sensitive enough to detect sediment-mass concentrations of only a few milligrams per litre (mg/l). To be operated under adverse environmental conditions the instrument must be not only sensitive but also responsive to a wide range of concentrations. The required performance appears to exceed, by a considerable margin, state-of-the-art capabilities of the entire instrumentation field.

Transmission, recording, and processing of transducer-generated data have been advanced through both private and industrial research, and a comparable research effort may be required to improve sensors needed to measure directly suspended-sediment concentration. Pending development of improved sensors, the sensitivity of presently available sensors could be enhanced by connecting them to calibrated sediment concentrators.

Smith, O. R. 1939. Placer mining silt and its relation to salmon and trout on the Pacific Coast. Trans. Am. Fish. Soc. 69:225-230. (OR)

Renewed activity in the placer gold mining country of the Pacific Coast States has raised the question of how much harm silt does to salmon and trout. The effect silt may have on migrating adult fish, on the selection of spawning places, and on the survival of fish food, is discussed. The conclusion is drawn that silt, whether from placer mining or natural erosion, is harmful to salmon and trout if it is heavy enough to form a layer on the stream bottom or if it persists during periods between floods.

Sprules, W. M. 1947. An ecological investigation of stream insects in Algonquin Park, Ontario. Publ. Ontario Fish. Res. Laboratory, No. 69, Univ. Toronto Press, Toronto, Can. (OR)

The effect of several ecological factors in the qualitative and quantitative distribution of stream insects in Algonquin Park, Ontario, was determined from data obtained by the use of the cage-trap method of sampling the emergence of insects from unit areas in streams, at regular daily intervals.

Incidents that induced significant alterations in the physical nature of the streams were accompanied by marked reductions in the total insect population and a change in the faunal composition of the affected areas. Such incidents included a severe freshet, cessation of flow and subsequent desiccation of the stream bed, and transformation of a shallow rocky riffle into a deep sedimented pool by construction of a beaver dam.

A correlation was found between the total number of species in rocky riffle areas at different distances from the source, and the average water temperatures. The linear distribution of species was delimited by the water temperatures obtaining in different sections of the stream and this was correlated with the thermal tolerance of the immature stages.

Within the limits set by temperature the distribution of species was affected by other factors including rate of flow and nature of the bottom, two factors which are closely interrelated and fundamentally inseparable. The diversity of the fauna decreased from rubble, through gravel, and muck, to sand as the variety of utilizable microhabitats decreased. The observed distribution on different types of bottom was related to habitat preference and associated morphological adaptations in the species.

The seasonal emergence periods of different species were segregated and the species emerged in the same sequence each year. The date of first emergence and the length of the emergence period of a species differed from year to year and were determined by annual variations in water temperature.

The diurnal emergence of species showed a similar segretation in general, in that any one species emerged at the same time each day while different species emerged at different times. The maximum total emergence from a rapids during mid-summer occurred throughout the evening hours and the most important causal factor involved seemed to be a reduction in light intensity.

It has been suggested that the number of indivduals present in any area depends primarily on the utilizable surface area of bottom particles exposed to the water.

Stephan, C. E., and D. I. Mount. 1973. Use of toxicity tests with fish in water pollution control. Pages 164-177 *in* Biological Assessment of Water Quality, ASTM STP 528. Am. Soc. Testing Mats. (OR)

The recent growth of interest in water pollution control programs has fostered the development of applied fish toxicology. One of the functions of applied fish toxicologists is to make the best possible decisions concerning the effects of pollution on fish based on existing data. A second function is to help make available the additional data most needed for the protection of important species of fish. A third function is to evaluate the usefulness of specific toxicity tests and ways of using them to fulfill needs that have been identified and to suggest improvements in existing tests or new tests that should be developed. The acute mortality test provides data that are useful in some situations, but the chronic test which studies effects of a toxic agent on survival, growth, and reproduction is probably the most useful toxicity test for estimating long-term safe concentrations. Other important adverse effects that should be studied include avoidance, flavor impairment, and the accumulation of toxic residues.

Stocker, Z. S. J., and D. D. Williams. 1972. A freezing core method for describing the vertical distribution of sediments in a streambed. Limnology and Oceanography 17:136-138. (OR)

A new technique is described for obtaining in situ samples of substrate from stony streambeds, using liquid nitrogen to freeze the substrate around a standpipe driven into the bed.

Various physical parameters are calculated for the substrate obtained.

Straub, L. G. 1936. Transportation of sediment in suspension. Civil Eng. ASCE J. 6(5):321-323. (OR)

Although the principles underlying the transportation of sediment in suspension have been slow in yielding to mathematical analysis, considerable information of practical value on the subject has been obtained through research and experimentation. In the present article Dr. Straub outlines some of the findings of one such study--the manner in which particles of various diameters distributed themselves in a vertical section, the effect of certain changes in the chemical composition of the water on the mechanical composition of the suspended load, and the relation between the stream discharge and the quantity of sediment in suspension. He also touches briefly on the selection of a model law to insure similarity in laboratory studies of sedimentation basins.

Stroud, R. H. 1967. Water quality criteria to protect aquatic life: A summary. Proc. Symposium on water quality criteria to protect aquatic life. Am. Fish. Soc., Spec. Pub. 4. Pp. 33-37. (OR)

A definition of water pollution must include the factor of impairment of water for any beneficial use by man. Our concern is rightly centered on water quality for maintenance of vigorous populations of aquatic life, especially the fishes.

Fishery scientists must be willing to interpret data concerning probable tolerance limits for the critical factors influencing fish life. Exact numerical criteria for most environmental factors are not known at the present time; consequently safety factors must be proposed to allow for variation due to local conditions and unknown interaction.

Stuart, T. A. 1953a. Spawning migration, reproduction, and young stages of loch trout (*Salmo trutta* L.). Scottish Home Dep., Freshwater Sal. Fish. Res., No. 5. 39 pp.

Ova of *Salmo trutta* L. placed early in development in silty water "attracted" fine silt particles which adhered to the chorion, turning the eggs from pearly and glossy to darkly coated. All ova in this condition died without hatching. Natural sediment, carmine powder, and finely divided carbon all gave the same result.

Eyed ova survived above conditions for 48 hours to hatch to healthy alevins.

Newly hatched alevins cleared silt from their immediate vicinity by movements of the tail and pectoral fins.

After developing use of the mouth and gills, alevins were observed binding silt in mucous and extruding it through gill slits or by coughing.

a. Continuous applications inflamed gill membranes.

b. Death always resulted from continuous silt applications.

Concluded that excesses of silt are not injurious provided they only occur at intervals.

Stuart, T. A. 1954. Spawning sites of trout. Nature, London 173(4399): 354.

The redd selection of trout in an artificial pool was observed. The observations support the opinion that spawners actively seek high oxygen and water influx sites for egg deposition.

Swanston, D. N. 1971. Principal mass movement processes influenced by logging, road building, and fire. Pages 29-40 *in* James Morris, ed. Proc. of a Symposium--Forest Land Uses and Stream Environment. Ore. State Univ., Corvallis, Ore. (OR)

Dominant natural soil mass movement processes active on watersheds of the western United States include: 1) Debris avalanches, debris flows and debris torrents; 2) slumps and earth flows; 3) deep-seated soil creep; and 4) dry creep and sliding. A dominant characteristic of each is steep slope occurrence, frequently in excess of the angle of stability of the soil. All but dry creep and sliding occur under high soil moisture conditions and usually develop or are accelerated during periods of abnormally high rainfall. Further, all are encouraged or accelerated by destruction of natural mechanical support on the slopes. Logging, road building, and fire play an important part in initiation and acceleration of these soil mass movements. Road building stands out at the present time as the most damaging activity, with soil failures resulting largely from slope loading, back-slope cutting, and inadequate slope drainage. Logging and fire affect stability primarily through destruction of natural mechanical support for the soils, removal of surface cover, and obstruction of main drainage channels by debris.

Sylvester, R. O., and C. A. Rambow. 1968. Methodology in establishing water quality standards. Pages 110-122 *in* T. H. Campbell and R. O. Sylvester, eds. Water Resources Management and Public Policy. Univ. Wash. Press, Seattle. (OR)

The methodology for establishing water-quality criteria as presented here was done for the State of Washington where most waters do not suffer from damaging pollution. Some aspects of the methodology may be more difficult to apply in regions where most waters are more severely damaged by pollution. The authors believe, however, that the basic philosophy and rationale is applicable to all waters, although this involves a profound change in most present practices for water-quality control. They further believe that this approach is the only practicable method of achieving or maintaining high-quality water for all to use and enjoy.

A comparison of the goal and standard values, presented in Table 11, with present water quality and minimum recorded water quality in 40 principal stream reaches in the State of Washington gave the following results for nine selected parameters: In the case of present quality, about 92 percent exceeded goal values, six percent lay between goal and standard values, and two percent fell below standard values. In the case of minimum recorded water quality, about 73 percent fell above goal values, 11 percent between goal and standard values, and 16 percent below standard values.

Tagart, J. V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. M.S. Thesis. Univ. Wash., Seattle. 101 pp. (OR)

Survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence was measured over two spawning seasons, 1973-74 and 1974-75. Nineteen redds were trapped in eight tributaries of the Clearwater River, Washington.

Female coho were observed attending a redd and egg deposition was estimated from the length of those fish. A length-facundity relationship was developed from a stock of coho returning to the Washington State Department of Fisheries Soleduck River Salmon Hatchery. Redds were trapped with a cap of nylon net and survival was calculated from the ratio of the estimated egg deposition to total emergents.

The intragravel incubation environment was characterized by measuring gravel composition, permeability, and dissolved oxygen. Emergent fry were weighed and measured and length of the emergence period was recorded. These variables were analyzed using correlation analysis to detect the possible inputs of logging.

The composition of spawning gravels was heterogeneous in space and stable over time. Percent of gravel <0.850 mm was defined as "poor gravel" while the percent of gravel <26.9 mm and >3.35 mm was defined as "good gravel." Mean intragravel permeability ranged from 319 cm/hr to 4,440 cm/hr. Mean intragravel dissolved oxygen ranged from 8.6 ppm to 11.8 ppm.

The length of the emergence period ranged from 21 to 70 days. Peak emergence occurred from one to 46 days after first emergence. Mean fry length ranged from 37.5 mm to 40.1 mm. Mean dry fry weight ranged from 0.064 g to 0.081 g.

Survival-to-emergence ranged from 0.9 percent to 77.3 percent. Mean survival was 30.7 percent in 1973-74, 15.3 percent in 1974-75, and 22.1 percent over both years. Survival was inversely correlated with poor gravel and permeability and positively correlated with good gravel. Correlations of survival with gravel were significant in 1973-74 but not in 1974-75. Permeability was measured only in 1974-75.

"Good gravel" was found to be due to its positive correlation with permeability. Poor gravel was inversely correlated with dissolved oxygen and fry size. Fry size was positively correlated with dissolved oxygen.

Tarzwell, C. M. 1938. Factors influencing fish food and fish production in southwestern streams. Trans. Am. Fish. Soc. 67:246-255. (OR)

For the past two years surveys have been in progress in the mountain streams of the Southwest. These investigations included chemical analyses, quantitative counts of bottom food organisms, a study of the physical character of the streams, and studies of the fish such as species present, relative abundance, age, and growth rate. An intensive study is being made on two experimental streams, one of which has been improved to the practical limit and the other left in its original condition.

The surveys have shown that vegetative cover on the watershed and especially in the canyon bottoms is of great importance in maintaining productivity. Vegetative cover is essential for retaining moisture and preventing severe floods which have been found to be the outstanding limiting factor in southwestern streams. Floods not only roll and grind the bottom materials and widen the stream bed, destroying pools and cover, but they also sweep away rich organic materials essential for an abundant bottom fauna and deposit light-colored inorganic silt which is almost barren of life. It has been found that streams not subject to severe floods for some years are much richer than those streams having frequent floods.

Studies made on the experimental streams clearly demonstrated this fact. These two streams--Upper Tonto Creek and Horton Creek--are similar in character and water supply. The unimproved stream, Tonto Creek, is however, 0.2 mile longer and has a larger flow. Formerly it was considered the better fishing stream. Since improvement, however, an intensive creel census and food studies have shown that the improved stream, Horton Creek, is now the better stream. Last year it was found from food studies made at different times throught the year that Horton Creek had an estimated yield of over 300 pounds more food than Tonto Creek. Also, the creel census revealed that Horton Creek yielded a greater number of fish. In addition, the catch per hour was greater on Horton Creek and the average total number of fish for each fisherman was greater. Scale studies reveal that prior to improvement the growth rate of the fish was more rapid in Tonto Creek, but since improvement it is more rapid in Horton Creek.

On the average these two streams yielded about 50 pounds of trout to the acre of stream. At the market price for trout this is a return of $30.00 an acre for meat alone, not taking into consideration the recreational value. This return is very good as compared to any southwestern land and gives a more definite idea of the real value of the fish resources of the southwest.

Tarzwell, C. M. 1955. Water quality criteria for aquatic life. Second Ontario Indust. Waste Conf. Pp 50-82. (OR)

The establishment of water quality criteria for the protection of our valuable aquatic resources is a complicated and difficult problem. Since the basic objective of water quality criteria for the protection of aquatic life is to provide or preserve environmental conditions essential for the survival, normal growth, reproduction, and well being of aquatic organisms a knowledge of the environmental requirements of these organisms is essential for the establishment of such criteria.

Many of the activities of man have modified the aquatic environment. Among these are deforestation, unwise agricultural practices, overgrazing, and pollution. Our aquatic resources which produce billions of dollars yearly in revenues from sport and commercial fishing are a renewable resource worthy of our best efforts for preservation.

Siltation due to erosion has been and is a major pollutant. The solution of this problem by means of erosion control must be a cooperative effort among those agencies dealing with water, soil, and other natural resources.

Criteria for settleable solids and turbidity will depend largely on local conditions and will vary with the stream and the area.

Tarzwell, C. M. 1956. Water quality criteria for aquatic life. Pages 246-272 *in* Trans. Second Seminar on Biol. Problems in Water Poll. Robert Taft Sanit. Eng. Cent., Cincinnati, Ohio. (OR)

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Tarzwell, C. M. 1962. The need and value of water quality criteria with special reference to aquatic life. Can. Fish Cult. 31:35-41. (OR)

The first step in the program is research to determine the environmental conditions which are required for the survival, growth, reproduction, and general well-being of the important members of the aquatic biota. A knowledge of these requirements is basic to the setting of water quality criteria to insure their continued well-being.

In setting water quality criteria it is the extremes of environmental conditions that must be delineated because they determine the survival of an organism and the suitability of an environment. While criteria are needed to indicate safe levels for short exposure periods, stress should be laid on the determination of the levels of conditions which are not harmful under conditions of continuous exposure and which are conducive to the survival of the species. Criteria also are essential for maintaining conditions favorable to the organisms in the food chain.

Tarzwell, C. M. 1966. Water quality requirements for aquatic life. Pages 185-197 *in* Proc. National Symposium on Quality Standards for Natural Waters. School Publ. Health, Univ. Michigan. (OR)

It is usually very difficult or impossible to compare the results of past bioassay studies, because many workers failed to record their procedures, times of exposure, organisms used, and the quality of the dilution water. Uniform or standard procedures are needed. Flow-through tests, where the toxicant and the dilution water are constantly renewed, are essential for securing desired exposures over long periods.

Studies must be made to determine the allowable and favorable levels or concentrations of such environmental factors as DO, $CO_2$, pH, temperature, etc. The effects of toxicants on these levels must also be determined.

Tebo, L. B., Jr. 1955. Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the southern Appalachians. Prog. Fish. Cult. 17(2):66-70. (GS)

Logging influenced the bottom fauna of a small trout stream in the Coweeta Experimental Forest. Bottom fauna were selected to measure the effects of siltation on a stream community. Logging practices were those used commonly in the southeastern States. Results indicated that poorly planned road systems and skid trails result in a high rate of erosion and siltation in stream channels. Properly constructed roads will benefit the logger by reducing road maintenance.

Tebo, L. B., Jr. 1956. Effects of siltation on trout streams. Soc. Am. For. Proc. Pp. 198-202. (GS)

A study of the Coweeta Experimental Forest in western North Carolina showed that soil erosion and siltation reduced, and in severe cases, even destroyed the trout fishery by: (1) Inhibiting spawning success; (2) reducing the available food supply; and (3) changing the physical characteristics of the habitat so as to make it unsuitable for trout.

Truhlar, J. F. 1976. Determining suspended sediment loads from turbidity records. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. Pp. 7-65 to 7-74. (OR)

The Pennsylvania Department of Transportation and the U.S. Geological Survey are cooperating in several field studies to evaluate sediment-control measures used during highway construction. Among the parameters being monitored are suspended-sediment concentration and turbidity. Sediment loads are calculated from suspended-sediment and water-discharge data, but some sediment loads must be determined indirectly because it is virtually impossible to obtain sufficient suspended-sediment samples to define all runoff conditions adequately. Sediment discharge-water discharge correlation curves have proven unreliable for streams affected by highway construction, so an alternate method using the turbidity record was developed during these studies.

The field data reveal a good correlation between daily mean discharge-weighted turbidity and daily mean discharge-weighted suspended-sediment concentration. Turbidity is monitored and recorded continuously, and the daily mean discharge-weighted turbidity is calculated from the turbidity and water-discharge data. During periods when there are insufficient suspended-sediment data, the daily mean discharge-weighted suspended-sediment concentration is determined from the turbidity-sediment correlation and used with the daily mean water discharge to calculate a daily sediment load.

This method of determining sediment loads from the turbidity record suggests a possibility for computer computation of sediment loads. Instrumentation now in use for recording water-quality parameters on digital-punch tape could be used to record the output from a turbidimeter. Then, for streams having a good correlation between suspended-sediment concentration and turbidity, simultaneous water-discharge and turbidity data could be used to determine sediment loads by computer.

Tsai, Chu-Fa. 1973. Water quality and fish life below sewage outfalls. Trans. Am. Fish. Soc. 102(2):281-291. (OR)

Comparative studies of water quality and fish species diversity in stream locations immediately above and below the outfalls of 149 secondary sewage treatment plants were made in Virginia, Maryland, and Pennsylvania. Sewage chlorine and turbidity increment resulting from sludge were found to be major causative factors for fish species diversity reduction below the outfalls.

Tyler, R. W., and D. R. Gibbons. 1973. Observations of the effects of logging on salmon-producing tributaries on the Staney Creek watershed and the Thorne River watershed, and of logging in the Sitka district. Univ. Wash., FRI-UW-7307. 58 pp. (OR)

The principal objectives of this study were to gather data on the effects of clear cutting on the summer temperatures and insect production in small streams of southeast Alaska which provide rearing habitat for juvenile salmon, trout, and char. Additional data were collected on the populations of salmonids, concentrations of organic leachates, and on the composition of stream gravel. Subjective observations also were made of the effects of past and present logging operations on salmon-producing streams in the Sitka area. The report is divided into two parts: Studies in the Thorne River and Staney Creek watersheds (Fig. 1); surveys of logged watersheds in the Sitka district (Fig. 2).

The work fulfills part of a one-year contract between the Fisheries Research Institute and the Alaska Loggers Association.

Tywoniuk, N. 1972. Sediment discharge computation procedures. ASCE J. Hydraul. Div. 98(HY3):521-540. (OR)

The processes of sediment transport in an open channel have been described in literature by a variety of empirical and semitheoretical relations based on the physical and hydrodynamic factors of a flow system. These empirical relations, in the absence of direct measurements and of observations of environmental factors influencing sediment transport, are frequently used to estimate sediment transport rates and quantities. An attempt is made herein to provide an analytical summary of some of the recent and more accepted sediment transport concepts related to analysis and transport rates in flow systems such as rivers and streams.

The hydrodynamic behavior of sediment in a fluid flow is of importance in a variety of areas of water resources. Knowledge of this behavior is required in the proper engineering and economic design of projects relating to erosion and shoaling of rivers, irrigation canals and navigation channels. The economic life of reservoirs depends on the amount and type of sediment transported and on the rate and degree of deposition in the reservoir. The hydrodynamic behavior of sediment also affects the boundary resistance to flow and therefore the stage-discharge relationships in channels with mobile beds. More recently, the significance of sediment pollution has been realized. Assessment of pollution effects requires not only knowledge of the efficiency of the sediment as a barrier, but also knowledge of quantities and rates of sediment transport. Also, sediment pollution in the quantitative sense frequently results from the spreading of fines from dredging and filling operations and may result in severe damage to feeding grounds and other marine resources.

U.S. Environmental Protection Agency. 1973a. Water quality criteria. VI. Freshwater Constituents (aquatic life). 75 pp. (OR)

The Envirogenics Co., under sponsorship of the Environmental Protection Agency, has developed a new technique for establishing firm criteria for health risks associated with recreational water bodies.

Initial analysis of data required in this methodology has determined that scientifically valid standards for recreational water quality can be formulated that should replace the present rather arbitrary standards.

The basis of the method is a mathematical treatment of medical dose-response data in conjunction with the probability of exposure over a period of time to a given level of the potentially harmful "factor" such that a quantitative risk can be assigned to the recreational activity. Once a public health jurisdiction has established an acceptable level of risk (perhaps in association with Federal quality guidelines), curves produced by electronic data processing equipment can be used to ascertain whether a particular water should be open to the public.

While sufficient data have been found on both the health effects and the distribution of key factors to verify the effectiveness of the recommended procedure, information gaps prevent the immediate adoption of the system. The gathering of information to establish realistic standards for key health-oriented factors would be an undertaking that could be accomplished in a relatively modest program. Once the essential information is obtained, it will be possible to put into practice the new Envirogenics-developed criteria procedure with the most critical factors. This advancement would be of great significance to the entire field of water quality standards.

U.S. Environmental Protection Agency. 1973b. Methods for identifying and evaluating the nature and extent of nonpoint sources of pollutants. EPA 430/9-73-014. (OR)

Agricultural, silvicultural, construction and mining activities contribute several pollutant substances to surface and groundwaters, and thus share with other activities the responsibility for protecting the quality of this country's water resources. These sources are diffuse in nature and discharge polluting substances to the water via widely dispersed pathways. Procedures for ameliorating the pollution must accordingly deal with activities and materials which are spread over relatively large land areas.

The major pollutant is sediment, the soil materials which erode from the surface of the land and are transported to streams and reservoirs by runoff water. Cropland is the chief source of sediment on a total mass basis; 50 percent or more of the sediment deposited in streams and lakes is credited to agriculture. Construction and surface mining activities, however, yield large quantities of sediment in relatively small regions of impact; sediment from these sources can have a highly adverse impact on both the quality of water, and on costs of water supply and storm water management. Well managed forests are exceptionally free of erosion and sediment pollution, but soils in forests disturbed by natural disasters (fire) or by harvest of timber are erodible, highly so if timber harvest is poorly managed.

U.S. Environmental Protection Agency. 1973c. Processes, procedures, and methods to control pollution resulting from silvicultural activities. EPA Office Air Water Prog., Washington, D.C. EPA 430/9-73-010. 91 pp. (EPA)

Nearly 203 million hectacres in the United States are in forests managed primarily for the production of timber. The principal water pollutants from this land area are eroded mineral soil sediments transported in runoff; organic matter which is chiefly transmitted to the water by runoff; pesticides; fertilizers; fire retardant chemicals; and thermal pollution resulting from solar radiation. Of these pollutants, sediment, including both its organic and inorganic (mineral soil) constituents, is the greatest single cause of water quality degradation. Sediment additionally acts as a carrier of such pollutants as pesticides and phosphorus. Control of erosion due to runoff is thus the most important aspect of control of pollution from forests.

Pollution from forests is nonpoint in origin, and defies control or treatment in the conventional sense. The treatment and control methodology is, therefore, principally the forest management system--the combination of practices involved in harvesting trees; log transport; reforestation; protection from fire, disease, insects and weed trees; and growth promotion. The practices in current use require adaptation to meet environmental goals as well as to achieve other objectives which govern forest land use.

U.S. Environmental Protection Agency. 1975a. Forest harvest-regeneration activities and protection of water quality. EPA, Region X, Seattle, Wash. (OR)

The report emphasizes summarization of research, currently applied prediction, prevention and control techniques, and guidelines/criteria for preventing water pollution.

Subregions have been defined due to the frequent need for specifying the applicability and relevance of the research information and "best available technology" presented. The subregional descriptions are presented in Section Two. As various aspects of the study are discussed, reference will be made when needed to situations in which the method is most applicable and, if possible, to circumstances or locations where the method may not be relevant. An alternative report structure would have been to include separate subregional sections for each method, but this approach was not taken due to the enormous potential for redundance.

Section Three summarizes the current forest practices utilized in Region X. Although these summaries are brief, they are sufficient to facilitate a general understanding of the report.

Section Four addresses the impact on water quality of the various forest practices presented in Section Three. Subsections are included concerning sedimentation, thermal pollution, and chemical pollution.

In Section Five of the report, various methods and approaches to planning and control are described. Emphasis is placed on providing the reader with summaries concerning: (1) The selection of silvicultural or logging systems based on water quality impact; (2) planning approaches and simulation models; (3) specific operational, design or planning constraints; and (4) the information requirements for monitoring, prediction or planning purposes.

U.S. Environmental Protection Agency. 1975b. Logging roads and protection of water quality. Report compiled by Arnold, Arnold and Associates, and Games and Moore, Seattle, Wash. 306 pp. (NTIS)

This report is a state-of-the-art reference of methods, procedures and practices for including water quality consideration in the planning, design, construction, reconstruction, use and maintenance of logging roads. Most of the methodology also is applicable to other forest management roads. The report is divided into two parts. The first part provides general perspective on physical features and conditions in Environmental Protection Agency Region X which are relevant to water quality protection and logging roads. The second part outlines specific methods, procedures, criteria and alternatives for reducing the degradation of water quality. Topic coverage in this part includes road planning, design, construction and maintenance including the use of chemicals on roads. Silvicultural activities are one category of water pollution from nonpoint sources described in Public Law 92-500. Of all silvicultural activities, logging roads have been identified as the principal source of man-caused sediment.

USDA Forest Service. 1963. Composition of streambed gravels. USDA For. Serv., Juneau, Alaska. 3 pp. (OR)

The purpose of obtaining gravel samples from Lemon Creek on the Glacier Highway near Juneau, was to get a preliminary idea of the amount of fine materials in the streambed.

USDA Forest Service. 1965a. Analysis of streambed composition. Div. Resource Mgmt., Branch Wildl. Mgmt. (mimeo). 3 pp. (OR)

The technique of sampling streambed gravels and analyzing streambed composition is useful for Forest personnel in the event they wish to measure the amount of fine materials in salmon spawning areas. The purpose of gravel sampling is to detect changes in streambed composition with time or from place to place within a stream.

These instructions tell what equipment to use, how to select areas to be sampled and how to sample streambed gravels.

USDA Forest Service. 1965b. Sensitivity of salmon embryos to agitation and shock. USDA For. Serv., Juneau, Alaska. 4 pp. (OR)

Recently, in connection with blasting accompanying road construction, questions have arisen regarding the sensitivity of salmon embryos to shock. This brief report summarizes research findings for the information of Forest personnel who may come in contact with this particular problem and discusses management implications involved in blasting.

Vanoni, V. A. 1974. Factors determining bedforms of alluvial streams. ASCE, J. Hydraul. Div. 100(HY3):363-374. (OR)

Based on the analysis of laboratory and field data, it appears that the following three parameters are important ones in predicting the bed forms generated by flows over sand beds: $d/d_{50}$, $F = V/\sqrt{gd}$, and $R_g = d_{50}\sqrt{gd_{50}}/\nu$, in which $d$ = flow depth; $d_{50}$ = median size of sand; F = Froude number of flow; V = mean flow velocity; $g$ = acceleration of gravity; and $\nu$ = kinematic viscosity of the water.

The fact that the three variables $d/d_{50}$, F, and $R_g$ predominate in determining the bed form agrees with the results of several workers who expressed sediment discharge and friction factor in terms of these variables or essentially equivalent ones.

Laboratory studies indicate that the size distribution of the bed sediment also affects the bed form although the relative importance of this factor is not known. Under some conditions the broadening of the size range of the sediment (increasing the geometric standard deviation, $\sigma_g$ alone causes a change in the bed form.

The data analyzed herein did not make it possible to determine the effect of channel width and grain shape and density on bed form.

Van Oosten, J. Turbidity as a factor in the decline of Great Lakes fishes with a special reference to Lake Erie. Trans. Am. Fish. Soc. 75:281-322. (M)

Fish live and thrive in waters with turbidities that range above 400 ppm and average 200 ppm. The waters of the Great Lakes usually are clear except in Lake Erie where the turbidities of the inshore areas averaged 37 ppm; the turbidities of the offshore waters averaged less. Lake Erie waters were no clearer 50 years ago than they are now. In fact, the turbidity values are less now than they were in earlier years; the annual average of the inshore waters dropped from 44 ppm before 1930 to 32 ppm in 1930 and later, and the April-May values decreased from 72 ppm to 46 ppm. Any general decline in the Lake Erie fishes cannot be attributed to increased turbidities. Furthermore, these turbidities averaged well below 100 ppm and, therefore, were too low to affect fishes adversely.

Turbidity in the open waters of Lake Erie is primarily the result of wave action induced by winds. River discharge is a minor factor even in the western end of the lake. Other probable factors are plankton, the eastward movement of the water mass, currents, seiches, and possibly bacteria. Wave action is undoubtedly the dominant agency in soil erosion along the shores of all of the Great Lakes.

No evidence exists that fluctuations in the abundance of zooplankton, the basic food of fishes, and of the fishes themselves are positively correlated in Lake Erie or that the plankton crop in this lake is ever in short supply. On the contrary, all available evidence shows that Lake Erie is comparatively rich in plankton and that the western end in spite of its turbidity is richer than the eastern. Some factor other than turbidity dominates the basic productivity of western Lake Erie.

With respect to turbidity Lake Erie has not become less suitable for fishes. This conclusion also receives support from the study of the fishes themselves. It was demonstrated that the growth of the western Lake Erie fishes compared very favorably with that of fishes in the other Great Lakes or similar waters. It was shown further that the known occurrence of relatively strong year classes in this lake was not consistently associated with low turbidities and conversely that the known low turbidities of the Lake Erie waters were not always accompanied by the large year classes. Also, contrary to the "turbidity theory," certain clear-water varieties, such as the walleye, have increased tremendously in recent years in Lake Erie, whereas the supposedly turbid-water forms, such as the sauger, have decreased in abundance. Reference was made to Doan's work, wherein he attempted to show correlation between turbidity and abundance for several species of Lake Erie fish but failed to do so except for the sauger where he reported a positive correlation. With respect to the productivity of fishes Lake Erie ranks first among the Great Lakes, and the western end in spite of its greater turbidity surpasses the eastern. As judged by certain accepted standards of water suitability, Lake Erie ranks high, and the western end again surpasses the eastern. Finally, it was pointed out that fishes which inhabit the clear waters of the Great Lakes declined as well as those which live in the more turbid waters and that turbidity, therefore, cannot be a factor in the depletion of all Great Lakes fishes. Furthermore, the reduction in abundance repeatedly has been associated with increased fishing intensity.

All of the evidence indicates, then, that soil erosion on farms and the turbidity of the water were not major factors, if operative at all, in the decline of Great Lakes fishes and that they did not make Lake Erie unsuitable for fish life.

Vaux, W. G. 1962. Interchange of stream and intragravel water in a salmon spawning riffle. U.S. Fish Wild. Serv., Spec. Sci., Fish. No. 405. 11 pp. (OR)

Studies of interchange of stream and intragravel water were conducted in 1957, 1958, and 1959 as part of a project that is supported by the Bureau of Commercial Fisheries to study the effects of logging on pink salmon production. Interchange was first qualitatively demonstrated in a salmon spawning riffle in Indian Creek in southwestern Alaska. Then, experimental research was carried on at the University of Washington Chemical Engineering Laboratory to determine variables that control interchange and, finally, additional field studies in Indian Creek provided a qualitative verification of dependence of interchange on stream gradient and other factors.

The theory of interchange postulates that steps involved in physical transport of free oxygen to intragravel water are (1) dissolution of atmospheric oxygen into stream water, (2) transport of oxygenated water to stream bottom, and (3) interchange of oxygenated water from the stream into the porous gravel interior. Factors controlling interchange are (1) gradients in stream surface profile, (2) gravel bed permeability, (3) gravel bed depth, and (4) bed surface configuration.

This theory was partially verified in the field as follows:

1. Interchange was traced by following intragravel movement of dyed water through a study riffle. Water was tagged with dye, and its direction of flow mapped by appearance in standpipes placed in the stream at various locations and depths.

2. Downward interchange was detected by (1) placing a capsule filled with fluorescein dye on the stream bottom and observing dye downdraft, and (2) introducing dye through a standpipe six or more inches below the gravel surface and tracing its movement by detection in standpipes at greater depths.

3. Upward interchange from gravel to stream was followed by introducing dye below the gravel surface and tracing its direction of flow through appearances in pipes at lesser depths and at the gravel surface.

Direction of interchange depends on stream surface profile and bed surface configuration:

1. Direction of interchange in that part of a riffle with a concave surface (stream gradient decreases in direction of flow) was upwards--intragravel to stream.

2. Direction of interchange in that part of a riffle with a convex surface (stream gradient increases in direction of flow) was downwards--streams to intragravel.

3. Direction of interchange under the troughs of standing waves created by irregularities in the streambed was upwards; intragravel to stream. Direction of interchange under crests of waves was downwards--stream to intragravel.

Vaux, W. G. 1968. Intragravel flow and interchange of water in a streambed. U.S. Fish Wildl. Serv., Fish. Bull 66(3):479-489. (OR)

The chemical quality of intragravel water in streams--the environment of salmon eggs, embryos, and alevins--is influenced by the rate of interchange of stream water and intragravel water. Factors controlling the direction and magnitude of flow or interchange of this water were identified in this study. Equations describing motion of waterflow within the streambed under specified boundary conditions are developed, and tests of the mathematical model with an electrolytic bath analog model are described.

The direction of waterfow within a streambed and the interchange of water between the bed and the stream depend primarily on the permeability, depth, and longitudinal profile of the porous streambed. Water upwells where permeability or depth of gravel decreases in the direction of streamflow and where the longitudinal bed profile is concave. Water downwells where permeability or depth of gravel increases in the direction of streamflow or where the longitudinal bed profile is convex.

Von Tumpling, W. 1969. Suggested classification of water quality based on biological characteristics. Pages 279-290 *in* S. H. Jenkins, ed. Advances in Water Pollution Research. Fourth Int. Conf. Water Poll. Res., Proc. Int. Assoc. Water Poll. Res, Pergamon Press, New York. (OR)

The recommended classifications currently consider only the biological state and oxygen balance, the most important criteria of water quality. It is now apparent that such other problems of water pollution as toxicity and salinity must be considered to an increasing degree. Where these conditions are present, biological methods can provide an exact basis for classification of water quality. For determination of toxicity, physiological methods have been developed by several authors (Knöpp, Offhaus, Reimann), and the influence of toxic waste on the biological state of waters can be determined by ecological investigations (Kothe) as well as by physiological tests (Knöpp). To describe the influence of saline wastes and salinity on the biological state of rivers the results of Ziemann are of great interest, because he provided that there exists a linear correlation between the logarithm of salinity and the associations of diatoms. It is to be hoped that for toxicity and salinity also the synthesis of chemical and ecological as well as physiological analyses will provide a comprehensive basis for evaluating water quality.

A statistical investigation of diverse parameters of water quality and a consideration of the dynamic aspects of biochemical metabolism in waters enables one to relate precisely the biological and chemical analytical data. This synthesis provides a sound basis for the classification and for the restoration of water quality, which is the ultimate intention of water pollution control.

Wagner, Richard. 1959. Sand and gravel operations. Pages 34-35 *in* E. W. Eldridge and J. N. Wilson, eds. Proc. Fifth Symposium--Pacific Northwest on Siltation--Its Sources and Effects on the Aquatic Environment. Portland, Ore. (OR)

Normal turbidity upstream indicated that the water was clear and the bottom free from silt. Immediately downstream the turbidity ranged from 91 ppm and 102 ppm of suspended solids. The introduced sedimentation caused a marked reduction in the aquatic insect population. Quantitative analyses of bottom samples showed population reduction 75 to 85 percent below the gravel operation. The reduced insect population in the silt deposited in the gravel has created a condition which has eliminated two basic needs (food and cover) for young trout and salmon. This, in turn, will reduce survival rates of these fishes. Although the silt deposits in this area below the operation and the turbidity values were lower than some accepted standards elsewhere in the country, they still appear to be too high for reasons given above. Tests showed, however, that where dragging was restricted to the cove area behind the dyke, turbidity and silt were not so harmful as where the draglining was taking place in the main channel.

Walkotten, W. J. 1973. A freezing technique for sampling streambed gravel. USDA For. Serv., Res. Note, PNW-205. 7 pp. (OR)

This stream sediment sampling method removes a nearly undisturbed, stratified sample containing stream gravel, intergravel water, and organic material and allows sampling in rocky streambeds. The equipment is inexpensive, easy to assemble, and portable.

Walkotten, W. J. 1976. An improved technique for freeze sampling streambed sediments. USDA For. Serv., Res. Note, PNW-281. 11 pp. (OR)

Equipment and operational improvements were made in the technique of freeze sampling stream sediments. The sampling procedure is routine, reproducible, and provides high quality samples. The equipment is now lighter, more reliable, and safer to use. The sediment sample obtained represents an undisturbed uniform vertical profile containing the bed material and water. Samples can be taken in deep water, through ice, and at other difficult locations. The equipment costs about $250.

Wallen, I. E. 1951. The direct effect of turbidity on fishes. Bull. Okla. Agric. Mech. Col., Arts Sci. Studies, Biol. Ser. No. 2, Vol. 48. 27 pp. (M)

Concentrations of montmorillonite clay killed most test fish (16 species) at 175,000 to 225,000 ppm in 15 to 120 minutes. Most fish survived concentrations up to 100,000 ppm. Behavior patterns elicited by increasing turbidity concentrations (20,000 ppm to 225,000 ppm) had four stages:

1. Surfacing for short periods and gulping air and water.

2. Surfacing for several minutes and losing equilibrium.

3. Floating on side at surface for up to 30 minutes and occasionally trying to swim.

4. Floating on side on surface with attempts at opucular and pectoral movement followed by death.

Mortalities showed gills clogged with silt and clay particles. Montmorillonite clay at naturally occurring turbidities was not shown to be lethal to juvenile or adult fish as concluded by the author.

Wells, R. A., and W. J. McNeil. 1970. Effect of quality of the spawning bed on growth and development of pink salmon embryos and alevins. U.S. Fish Wildl. Serv., Spec. Sci. Rep., Fish. 616. 6 pp. (OR)

Among three segments of the spawning ground in Sashin Creek, southeastern Alaska, the largest and fastest developing embryos and alevins of pink salmon, *Oncorhynchus gorbuscha*, came from spawning gravels characterized by high levels of dissolved oxygen in intragravel water. The high oxygen levels occurred in a stream segment which has a relatively steep grade and coarse materials in the bed. No differences in the water temperature were observed among the three segments.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Board Can. 11(6):933-953. (OR)

By using standpipes set 12 inches into the stream bottom the oxygen content and apparent velocity of the gravel water in the controlled-flow section of Nile Creek were observed. Values of dissolved oxygen content and velocity that just supply the full oxygen demand of salmon eggs were defined. The high mortalities of chum salmon eggs in pre-eyed stage, that have been found in certain areas, may be explained on the basis that oxygen demands of 0.00013 to 0.0003 mg/egg/hr at temperatures of 0.1° to 8.2°C were not being met, owing to very low oxygen content or very low apparent velocity of the water in the gravel. Values as low as 0.2 ppm and 2 mm/hr were recorded. A portable gravel-water sampler is described, which can be used (1) to obtain samples of subsurface water for the determination of dissolved oxygen; and (2) to calculate apparent velocity of gravel water from rate of dilution of an added dye.

Wickett, W. P. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. J. Fish. Res. Board Can. 15:1103-1126. (OR)

The relation between stock and numbers of spawners is obscured by annual environmental changes. Stream discharge at the time the spawners are migrating upstream, at the time when the eggs are in the early stage of incubation, and extreme discharge during the period eggs and alevins are in the gravel can impose an eight-fold variation in the stock resulting from a given number of spawners in one area. Ocean conditions soon after the fry enter the sea have been observed to increase or decrease survival by a factor of 3. The density of spawners that produces the greatest numbers of fry is related to the average permeability of the stream bottom. Preliminary data indicate that more spawners could be used to advantage in most areas of the coast.

Wickett, W. P. 1959. Effects of siltation on success of fish spawning. Pages 16-22 *in* E. F. Eldridge and J. N. Wilson, eds. Proc. of Fifth Symposium--Pacific Northwest on Siltation--Its Source and Effects on Aquatic Environment. Portland, Ore.

Some general relationships are recognized between spawning success and siltation. Silt (particles <2 mm) reduces egg survival by interfering with intragravel flow and alevin survival by entombment. Specification of grading curves with the best combination of use by adults, intragravel flow ease of fry emergence and wide range discharge stability are urgent needs.

Williams, R. P. 1975. Erosion and sediment transport in the Owens River near Bishop, California. USGS Water Resources Investigations 49-75. 22 pp. (OR)

Closure of Pleasant Valley Dam in 1954 has almost eliminated the supply of gravel to the 16-mile (25.7-kilometre) study reach of the Owens River. Because of armoring of the channel, scour has been limited to approximately 1 foot (0.3 metre) in the upper 2.3 miles (3.7 kilometres). Bedload transport in the upper half of the reach is dependent on the hydraulics of a section and the availability of material. Ninety-eight percent by weight of bedload transported between sites 1 and 6 is finer than eight millimetres, although bed material is only 6-12 percent finer than 8 millimetres. Bank material is finer than 16 millimetres. Bank erosion is accelerated by wide ranges in flow release. The bank-erosion rates interpreted from aerial photographs indicate average annual erosion rates of 750 tons (680 tonnes) from 1947 to 1967, 1,970 tons (1,790 tonnes) from 1967 to 1968, and 2,020 tons (1,830 tonnes) from 1968 to 1971. These rates are compatible with the water discharge-sediment discharge relation developed from field data collected during 1972-73.

Williams, D. D., and H. B. N. Hynes. 1974. The occurrence of benthos deep in the substratum of a stream. Freshwater Biol. 4:233-256. (OR)

(1) The vertical distribution of the benthic fauna of the Speed River, Ontario, was studied over a 13-month period from October 1970 to October 1971. Various physical and chemical parameters of this interstitial environment were also measured.

(2) Several new techniques for sampling the interstitial environment of rivers were devised. These methods and their relative efficiencies are considered.

(3) The validity of the terms 'hyporheal' and hyporheic' are discussed and the term 'hyperheos' is offered to replace the former.

(4) A brief resume of interstitial sampling methods is given with comments on their limitations for sampling deep heterogeneous substrates.

(5) Chemical parameters are thought to be more important in the control and distribution of the fauna than physical parameters.

(6) It is suggested that many larvae of stream-dwelling chironomids have overwintering stages when they penetrate deep in the substrate to: (a) actively feed on the trapped organic detritus; (b) follow an optimum temperature for development.

(7) It is suggested that the shape of an organism determines its success as a hyporheic form and examples are given.

(8) The numbers of animals occurring in the sub-benthic populations are shown to be very large indeed. For the Speed River, estimates of between 184,760 and 797,960 animals/$m^3$ are made for different times of the year. Dry weight biomass is estimated to vary between 30.9 g and 253.2 g/$m^3$ throughout the year.

(9) Sub-benthic or hyporheic populations are shown to exist in at least three other Canadian rivers. Some of the animals found are shown to be common to two or more of these rivers.

(10) The inefficiencies of many conventional benthic samplers in sampling the total biomass of certain streams with hyporheic populations is discussed.

Williams, R. W., R. M. Laramie, and J. J. Ames. 1975a and 1975b. A catalog of Washington streams and salmon utilization. Vol. 1, Puget Sound Region. Vol. 2, Coastal. Wash. Dep. Fish.

Volumes 1 and 2 with provisions for supplemental updates cover approximately 13,700 streams in the Puget Sound and coastal areas of Washington. Stream measurements and maps as well as river mileages, barriers and useful landmarks are included. General characteristics considered as limiting factors are listed as: flooding, low summer flows, erratic streamflows, unstable streambeds, production areas lost, water quality and temperature. Also included are fish inventories and distributions.

Willis, J. C., N. L. Coleman, and W. M. Ellis. 1972. Laboratory study of transport of fine sand. ASCE, J. Hydraul. Div. 98(HY3):489-501.

Results have been presented from 105 experiments in a laboratory flume with 0.1-mm bed material for a depth range of about 0.4 feet to 1.2 feet (0.12 m to 0.366 m) and a discharge range of about 0.7 cfs to 4.25 cfs per foot of channel (0.065 $m^3/s$ - m to 0.395 $m^3/s$ - m) width. The concentration of the transported sediment depended in a rather complex way on the basic flow variables, depth and discharge rate. A graph of concentration versus discharge, with depth as a parameter, permitted the bed form regimes to be delineated.

The data were presented as a similitude relationship between the concentration and the Froude number of the flow. Whereas published data from investigations with somewhat coarser sands suggested unique curves of $\bar{c}$ versus f for all flow conditions, the data for this very fine sand described different relationships for depth of 0.7 feet (0.21 m) or less than for depths greater than 0.7 feet (0.21 m). For the deeper depths the transition from dunes to plane beds occurred at decreasing concentrations for increasing depths, and the plane-bed flow regime persisted at higher Froude numbers than for depths less than 0.7 feet (0.21 m). The data suggested separate functions for the three bed-form regimes, but the extended plane-bed relationship for Froude numbers above 0.6 may be due to limited length of test channel.

Wilson, J. N. 1960. Effects of turbidity and silt on aquatic life. Pages 235-239 *in* Trans. Seminar on Biol. Problems in Water Poll. Robert A. Taft Sanit. Eng. Cent. (OR)

The problem of siltation and excessive turbidity stemming from activities of man are widespread and difficult to control. As a guiding principle in establishment of water quality criteria for permissible concentrations of silt and turbidity in streams, certain percentage increases above levels at normal low flow in waters is suggested.

Wolman, M. G. 1974. Stream standards: dead or hiding. J. Water Poll. Control Federation 46(3):431-437. (NTIS)

Water quality is not easily quantifiable, but is rather dependent upon perception of use. While the public is attuned to attributes such as algae, murkiness, suds, foam, cans, glass, and debris, scientists try to measure river quality by standard parameters such as dissolved oxygen, acidity, temperature, dissolved solids, turbidity, and biological measures such as the diversity of species, size of the population, and complexity of the system. To translate quality objectives into standards is quite difficult. In addition, economic benefits, as opposed to costs are vaguely defined. Every water body has more than one polluter along with a number of pollutants, and reasonable standards must vary with perceived use of a particular river.

Wurtz, C. B. 1966. Water use for aquatic life. Pages 81-89 *in* Water Quality Criteria, ASTM STP 416. Am. Soc. Testing Mats.

Aquatic life in general is quite tolerant of deteriorated water. Aquatic organisms vary in their responses to environmental alteration from extreme sensitivity to equally extreme tolerance. Compared to the quality of water required for domestic and industrial use, the aquatic life of the nation is not very demanding. To protect all water-use interests pollution must be defined, criteria for natural waters developed, and standards for specific discharges fixed. It is probable that no single, equitable set of criteria for aquatic life can be established over a geographic area larger than the basin of a first- or second-order tributary of our major rivers. Water quality change brings about a concomitant biological change, but extreme conditions must exist and be persistent before aquatic life is eliminated. Environmental control is essential if optimal conditions for aquatic life are to be developed and maintained. Waste disposal, properly controlled, need not conflict with the use of water for aquatic life.

Wustenberg, D. W. 1954. A preliminary survey of the influences of controlled logging on a trout stream in the H. J. Andrews Experimental Forest, Oregon. M.S. Thesis. Ore. State Coll., Corvallis. 51 pp. (EPA)

The staggered-setting system of logging in mature Douglas fir stands affects trout environments. Findings included: 1. An increase in localized sediment reading the stream associated with maintenance and use of logging roads. 2. A lack of pronounced increases in sediment concentrations as a result of logging. 3. A fine silt consistency for most sediments. 4. A preponderance of sediment concentrations in the upper parts of small tributaries. 4. A greater disruption of streambeds from tractor logging than from high lead logging. 6. Severe scouring in logged streams during high flows in comparison with relatively undisturbed conditions in unlogged sections of the same streams. 7. The elimination of cutthroat trout populations in logged streams and adverse effects on aquatic insects for at least one year. 8. The possibility of reduction in water temperatures through the use of streamside buffer strips.

Yang, C. T. 1973. Incipient motion and sediment transport. ASCE, J. Hydraul. Div., 99(HY10):1679-1704. (OR)

Because of the importance of unit stream power to the study of sediment transport, the concept of unit stream power is further explored in this paper. Special attention is given to the problem of incipient motion, and the possibility of obtaining a dimensionless equation that can be used to predict the total sediment concentration for a given sediment and flow condition.

This study is limited to noncohesive natural sand with a median sieve diameter between 0.062 mm and 2 mm, a specific gravity of 2.65, and a shape factor of about 9.7, transported by water in an alluvial channel under equilibrium conditions. It is assumed that the energy slope can be approximated by water surface slope. Laboratory and field data collected by different investigators are used to verify the proposed theories.

Yorke, T. H. 1976. Ten years of experience with automatic pumping-sediment samplers. Proc. Third Fed. Inter-Agency Sedimentation Conf., March 22-25, 1976. Pp. 7-54 to 7-64. (OR)

The U.S. Geological Survey has used pumping-sediment samplers to study the sediment transport characteristics of small streams in Maryland for the last 10 years. Four different samplers developed by the Federal Inter-Agency Sedimentation Project were used to sample suspended sediment on five streams with drainage areas ranging from 1.2 to 54.6 square kilometres (0.47 to 21.1 square miles). A PS-62 sampler has been in continuous operation since its installation in 1966. The sampler provided satisfactory coverage for 139 of 220 storms between 1966 and 1975. Installation of a streamlined intake structure, commercial electrical power, and in-line battery chargers increased the reliability of the sampler from 32 percent in 1969 to 84 percent in 1973. It is estimated that the latest version of pumping samplers, the PS-69, would provide reliable service during 90 percent of the storms if the installation were properly designed and maintained.

Ziebell, C. D. 1960. Problems associated with spawning and growth of salmonids in Northwest watersheds. Proc. Seventh Symposium on Water Poll. Res., U.S. Dep. Health, Educ., Welfare, Portland, Ore. Pp. 28-32. (GS)

Our watershed problems fall into two basic categories, natural and manmade, which the author discusses with respect to spawning, incubation, and affiliated problems, as well as to fish growth problems emphasizing the need for more research and better control over logging operations.

Ziemer, G. L. 1973. Quantitative geomorphology of drainage basins related to fish production. Informational Leaflet No. 162, Dep. Fish Game (Alaska), July 1973. 26 pp. (OR)

This report covers the results of a study investigating the possibility of developing a classification index system for watersheds which would quantify their total composite salmon production potential. The premise was tested that, within a geologically and climatologically homogenous region, the water flow regimen of streams, and the channels that flow builds, is universally related to certain identifiable characteristics of their basins and drainages and that these control or indicate the level of fisheries production.

This study shows that a correlation between drainage system geometry and freshwater production factors for anadromous fishes can be shown, and an index expressing that relationship, in the case of pink salmon in Prince William Sound, has been developed.

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